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DISSERTATION

The early repetition effect as a marker of facial representations stored in memory and its sensitivity to changes in viewpoint

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ZUSAMMENFASSUNG

In Modellen der Gesichtererkennung [Bruce, 86c] wird eine Verarbeitungsstufe postuliert, auf welcher strukturelle Gesichterrepräsentationen im Langzeitgedächtnis (LZG) innerhalb von sogenannten Face Recognition Units (FRUs), abgerufen werden. Frühere Studien z.B. [Pfütze, 02] zeigten eine Komponente in den ereigniskorrelierten Potentialen (EKPs), welche die Aktivierung solcher FRUs anzeigen – der frühe Wiederholungseffekt (oder early repetition effect –ERE). Dieser zeigt sich bei wiederholter Darbietung bekannter Gesichter um 250 -350 ms mit frontaler Positivierung und temporal inferiorer Negativierung als ein EKP auf die zweite Präsentation. In Experiment I und II dieser Dissertation wurde der ERE als Maß der Aktivierung struktureller Gesichterrepräsentationen im LZG durch ein Prime-Target-Paradigma mit einer perzeptuellen Rückwärtsmaskierung validiert. Die Maskierung mit einem unbekannten Gesicht ergab im Vergleich zu einem zerwürfelten Gesicht und der unmaskierten Bedingung eine spezifische Topographie des ERE, die den gedächtnisbasierten Anteil des ERE widerspiegelt. Dieses Paradigma wurde in Experiment III eingesetzt, um die Blickwinkelabhängigkeit des ERE zu untersuchen. Die Ergebnisse deuten darauf hin, daß Gesichter durch mehr als nur blickwinkelabhängige, zweidimensionale Abbilder repräsentiert sind, da zumindest für Frontalgesichter ein ERE sogar über eine Blickwinkelabweichung von 90° gezeigt werden konnte. Dies ist vereinbar mit einer „dualen Strategie“ der Gesichtererkennung [O'Toole, 98], wobei sowohl Konfiguration als auch Einzelmerkmale eines Gesichtes abgerufen werden. Die Ergebnisse sind vereinbar mit Bruce und Young [Bruce, 86c], welche FRUs als Einheiten konzipierten, in denen konfigurale und einzelne Merkmale verschiedener Blickwinkel miteinander verbunden sind, was in diesem Sinn einer objektzentrierten, dreidimensionalen Speicherung eines individuellen Gesichts entspricht.

Schlagworte: Gesichtererkennung; früher Widerholungseffekt; Maskierung; Blickwinkelabhängigkeit

ABSTRACT

Models of face recognition [Bruce, 86c] postulate a processing stage where face recognition units FRUs are accessed. FRUs are thought to be structural representations of familiar faces stored in long-term memory (LTM). Previous work [Pfütze, 02], suggested the existence of a component in the event-related-potential (ERP) which signals FRU activation - the early repetition effect (ERE). The ERE can be observed when familiar faces are shown repeatedly, as an ERP around 250-350 ms that is more positive at fronto-central and more negative at inferior temporal sites for the second presentation of the face. In Experiment I and II of the present dissertation the ERE was validated as a marker of FRU activation in LTM by using a repetition priming paradigm with backward masking. Compared to the scrambled and non-mask conditions, the ERE revealed a distinguishable topography when an unfamiliar face interspersed prime and target, demonstrating contributions of face identity codes to the ERE. In Experiment III, this paradigm was used to analyse the viewpoint-dependency of the ERE. Results of Experiment III indicate that facial representations are more than viewpoint-dependent, two-dimensional images of a face, because even under a 90° view deviance between prime and target an ERE was detectable at least for frontal targets. This reconciles a dual-strategy in face recognition [O'Toole, 98]. Accordingly, facial representations can be assumed as a combination of image-based views, reflecting their configuration and single features. Results are in line with Bruce and Young [Bruce, 86c] who postulated that FRUs contain both features and configurations of distinct head angles in an interlinked manner. In that sense, FRUs can be described as three-dimensional analogues of the face they represent making object-centered recognition on an individual level possible.

Keywords: face recognition; early repetition effect; masking; viewpoint-dependence

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INHALTSVERZEICHNIS

FIGURES

TABLES

ABBREVIATIONS

A/D	analogue / digital
ANOVA	analysis of variance
cm	centimeter
EEG	electroencephalography
EOG	electrooculography
ERE	early repetition effect
ERP	event related potential
F	F-ratio
FFA	fusiform face area
fMRI	functional magneto-resonance tomography
FRU	face recognition unit
HERA	hemispheric encoding and retrieval asymmetry
Hz	hertz
IAC	interactive activation and competition
IOG	inverior occipital gyri
ISI	inter stimulus interval
kΩ	kiloohm
LRE	late repetition effect
LRP	lateralized readiness potential
LTM	long term memory
M	mean
m	meter
μV	microvolt
ms	milliseconds
MVPT	multiple views plus transformation
NRU	name recognition unit
OFA	occipital face area
p	level of significance
PDP	parallel distributed processing
PE	percentage of errors (error rate)
PET	positron emission tomography
PIN	person identity node
PRS	perceptual representation system
rCBF	regional cerebral blood flow
rTMS	repetitive transcranial magnetic stimulation
RT	reaction time
sec	second

SD	standard deviation
SCR	skin conductance respond
SOA	stimulus onset asynchrony
STM	short term memory
STS	superior temporal sulcus
VPP	vertex positive potential
vs	versus
v.v.	vice versa

1 INTRODUCTION

1.1 Topic and overview

In models of face recognition [Bruce, 86c] [Burton, 90], Bruce and Young [Bruce, 86c] postulate a processing stage where structural representations of familiar faces stored in long-term memory (LTM) within so-called face recognition units (FRUs) are accessed. Repetition priming studies [Pfütze, 02] [Schweinberger, 95] suggested the existence of a component in the event-related-potential (ERP), which signals FRU activation – the early repetition effect (ERE). When familiar faces are shown repeatedly, the ERP around 250-350 ms is more positive at fronto-central and more negative at occipito-temporal sites for the second presentation. The ERE is topographically distinguishable from a later component between 350 and 700 ms showing for primed faces an enhanced positivity at centro-parietal and an enhanced negativity at frontal electrodes - the late repetition effect (LRE). In contrast to the ERE, occurs the LRE after repetition priming and associative priming. Therefore, the LRE has been related to the facilitation in assessing semantic memory codes. The aim of this thesis is to specify properties of the ERE as reflecting the activation of facial representations on a pre-semantic level. Two objectives are focused upon: The first concerns the validation of the ERE as an indicator of the activation of structural representations of faces stored in LTM and FRUs, respectively. The second objective concerns the sensitivity of the ERE to changes in viewpoint with respect to profile or frontal view and to the learning view (frontal or profile). Provided that the ERE indicates the activation of facial representations in LTM, the ERE's sensitivity to changes in viewpoint and learning view would indicate how faces are stored in memory – by two-dimensional, viewer-centred and view-point-dependent images or by object-centred representations, as three-dimensional analogs of a face that allow face recognition invariant to the viewpoint. Experiment I and II aim at the validation of the ERE indicating the activation of facial representations in memory. When faces are repeated immediately [Schweinberger, 95] the ERE was detectable for both familiar and unfamiliar faces, still it was smaller for unfamiliar faces. If perceptual codes are extinguished between presentations by intervening unfamiliar faces [Pfütze, 02] or by face inversion [Boehm, 06a], the ERE was confined to familiar faces. This evidences that the ERE, as evoked by the immediate repetition of the same picture of a face, reflects a combination of two dissociable processes, the facilitated access to pre-existing representations of familiar faces

in LTM and facilitation perceptual processing of faces due to short term memory-STM [Boehm, 06a] [Boehm, 06b]. In Experiment I and II of the thesis a prime-target-paradigm was combined with perceptual backward masking to interfere perceptual-based priming when the target face is recog-nized. Experiment I analyses the impact of a facial mask that follows the prime imme-diately before a familiar and unfamiliar face is repeated. The ERE should only be detec-table for familiar faces, and priming due to perceptual STM can be excluded. Experiment II is to compare the impact of different mask types (unfamiliar face, scrambled face, grey rectangle) on the ERE directly, demonstrating contributions of perceptual priming (pictorial and structural codes) to repetition priming. In summary a familiarity specific ERE (Experiment I) that systematically decreases as the impact of different masks increases (Experiment II) validates the ERE as a marker of the activation of stored repre-sentations when repetition priming with backward masking using unfamiliar faces is used. The second objective of the thesis is based on the ERE's validation and focused in Experiment III. In Experiment III repetition priming with backward masking was applied to analyze the sensitivity of the ERE to changes in viewpoint that provide an insight into the underlying nature of facial representations. The question of viewpoint dependence of the ERE and the consolidation of structural codes (configuration and features) within a single representation is addressed by exploring the ability of the human visual system to generalize recognition from familiarized frontal or profile view to the unfamiliar profile or frontal view. According to Bruce and Young [Bruce, 86c], FRUs contain an interlinked set of structural codes including configural and featural information for distinct head angles, becoming active after any view of a familiar face is seen. In this sense they can be characterized as viewpoint-independent [Burton, 94]. Based on this and on theories that assume face recognition to be the encoding of both, feature-based as well as configuration-based information that are retrieved dependent upon the angle of view change [O'Toole, 98] [Valentin, 01] [Wallraven, 02]. An ERE after view change should be smaller compared to the ERE when the view did not change but should be still detectable. As the perception of facial configuration is susceptible to viewpoint changes face recognition across extreme changes in viewpoint (frontal to profile and v.v.) might be based on distinctive features being accessible from different viewpoints and extracted from the learning view. On the one hand, theories that rely on multiple views of two-dimensional images and their interpolation alone [Bülthoff, 92] might have to be

refused as at least two different views have to be encountered before to recognize a face from an unfamiliar viewpoint. On the other hand, theories that rely on object-centred representations, based exclusively on three-dimensional parts [Biederman, 87] are less able to account for face recognition as they disregard configural information processing and provide an account for recognition on a basic-level (faces as a stimuli-class) rather than within the homogeneous stimulus class of faces. Concerning the neural sources of the ERE, comparable topographies with respect to the same or changed viewpoint and to learning view would support the idea of consolidation of features and configuration according to different views into a single representation and in that sense of viewpoint-invariance in face recognition [Bruce, 86c] [Schwaninger, 02]. The results of the present thesis will not give a definite answer as to whether facial representations resemble object-centred, three-dimensional rather than viewer-centred, two-dimensional representations. Nonetheless, they can be considered as steps in this direction. The thesis is structured as follows: The theoretical part provides the reader with an understanding of FRUs as containing facial information on a pre-semantic level within the face recognition model by Bruce and Young [Bruce, 86c]. Supporting evidence for this model came from priming studies and the experiments in this thesis are based on repetition priming. The model of Burton, Bruce and Johnston [Burton, 90] provides the reader with the principle of priming. Consecutively the process of face recognition is introduced in the neuroanatomical way based on Haxby, Hoffmann and Gobbini [Haxby, 00]. This will be completed by results concerning lateralization in face recognition including the processing of viewpoint-invariant and viewpoint-dependent information. An excursus provides the interested reader with the controversially discussed issue of domain specificity in face recognition. Within this thesis faces are considered as a highly sophisticated object-class. Theories about the representations of objects and faces in memory concerning dimension and content are outlined and underpinned by empirical results. Conclusions are drawn with respect to the hypotheses and the experimental design in the present work. The methodo-logical background is to motivate the use of the paradigm and to provide the reader with description of ERPs being associated with face processing, including the ERE. Based on theory and methodological background hypotheses of the studies are specified and an over-view about the accomplished experiments is given. Following that Experiments including

results are outlined in detail and discussed. Finally, the section entitled further prospects is designed to inspire other experiments which could provide continuative data in this topic.

1.2 The process of face recognition

1.2.1 Functional approach – the notion of face recognition units

1.2.1.1 The functional model of face recognition (Bruce & Young, 1986)

Bruce and Young [Bruce, 86c] developed a theoretical model for the perceptual and cognitive processes involved when people recognize faces (see *Figure 1*). The model covers the perception and the derivation of any type of stored information from faces, as well as the retrieval of personal information, by defining functional components and their interaction. Bruce and Young [Bruce, 86c] determine seven distinct types of information as products of the operation of the functional components. Face recognition can be described as the sequential access of these different codes. They distinguish pictorial, structural, visually derived semantic, identity-specific semantic, name, expression and facial speech codes. The representation of identity seems to be relatively independent of the representation of the changeable aspects of a face. Otherwise a change in expression for instance could be misinterpreted as a change of identity. Still, Calder and Young [Calder, 05] argued that the separation of the two pathways is relative rather than absolute. Indeed, there is empirical evidence that person identification via the face occurs independently and in parallel from the identification of face expressions and lip-reading on one hand, [Young, 85b] [Young, 06] [Young, 86a] and that expression and identity facilitate recognition in an interactive way [Baudouin, 00] [Schweinberger, 98] [Wild-Wall, 08] on the other hand. Viewer-centred descriptions provide input to all of these processes that interact with the cognitive system. The cognitive system itself is not closer defined. Expression and facial speech codes also play a special role in face identification in general, but a minor role here. This thesis focuses upon the pre-semantic storage of facial information as being at the core of the identification route. Major importance is given to pictorial and structural codes as abstract descriptions forming facial representations – so called face recognition units (FRUs) stored in LTM. Semantic and name codes are of essential importance in recognizing a person's face successfully, but are not focused upon in this thesis. According to Marr [Marr, 82], who introduced a general model of visual perception, Bruce and Young [Bruce, 86c] distinguish between levels of integration and representation in the visual

system. Thus, the form of FRUs is explained by the idea of different levels of visual representation.

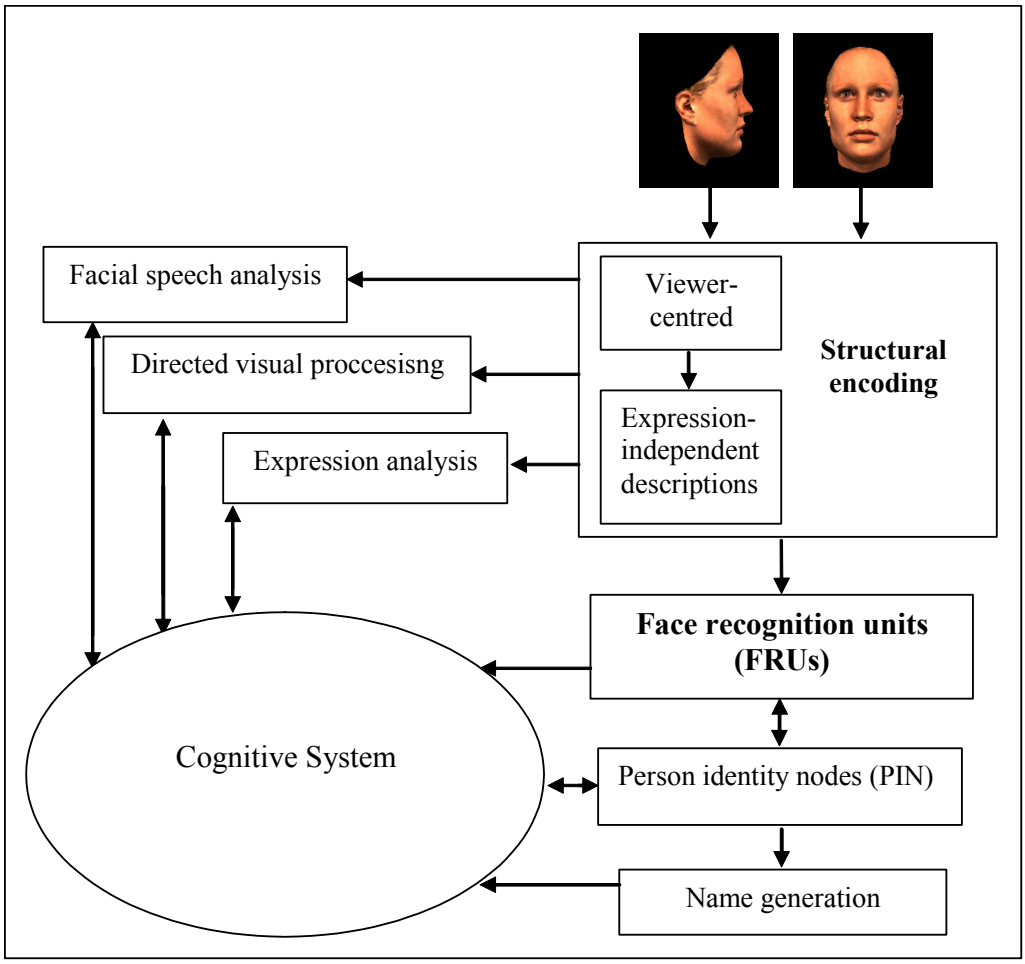

***Figure 1**: Functional model of face recogniton by Bruce & Young (1986)1*

The process of face recognition begins with pictorial and structural encoding of an actually seen face. That means in the first stage the formation of pictorial codes by integrating

[1] The model by Bruce & Young (1986) disregards the affective component in face recognition. Neuropsychological findings (Capgras delusion) led to the extension by aroute leading from FRUs to an affective response (Breen, Caine & Coltheart, 2000) and an integrative device component that compares the outcome of both routes [Ellis, 01]. Empirical support for the idea of FRUs that feed into a dual-route (cognitive / affective) system came from Herzmann, Schweinberger, Sommer & Jentzsch [Herzmann, 04].

information from successive fixations. It contains details of lighting, grain and flaws as well as the static pose and expression. Pictorial codes mediate recognition memory decisions of episodic memory for faces that have been previously seen. The authors regard the pictorial code as a general code formed for any visual pattern and are comparable to primal sketches at a first stage of perception according to Marr [Marr, 82]. After that, more abstract visual representations, so-called structural codes are established. Structural codes capture those aspects of the structure of a face that are essential to distinguish it from other faces.

Structural encoding produces viewer-centred descriptions and more abstract expression independent descriptions and can be associated with the formation of 2 ½ D-sketch-level as proposed by Marr [Marr, 82]. Viewer-centred descriptions provide information for both directed visual processing to derive visual semantic codes and abstract independent descriptions. Both are important for the processing of familiar and unfamiliar faces. Beyond that, unfamiliar face processing [Hancock, 00] is different to familiar face processing. Structural codes for familiar faces differ from those formed from unfamiliar faces, especially in feature saliency. Structural codes include information about features as local information and their spatial relations or global configuration [de Gelder, 01] [Leder, 00] [Wallraven, 02] [Schwaninger, 02]. Configural processing is thought to be critical for structural encoding of faces and can be easily disrupted by face inversion. Maurer, Grand and Mondloch [Maurer, 02] differentiate between featural processing (also called componential or analytic) and three types of configural processing: detecting the first-order relations that define a face (eyes above nose and mouth), holistic processing (relating the features into a gestalt) and processing second-order relations, meaning the relationship between the features. Whereas, for familiar faces internal features appear to be especially important and more elaborated, internal and external or “cardinal” features (e.g. hairstyle) are equally important for unfamiliar faces [Bonner, 03a] [Ellis, 79] [Young, 85b]. As suggested by Bruce & Young [Bruce, 86c] familiar faces are represented as structural codes containing mainly information about internal facial features, i.e. features and configuration. External features belong to change-able aspects and play a minor role in the formation of perceptual representations of faces.

When a face occurs repeatedly the visual representation alters from being an inflexible image-specific coding of a face equally reliant upon external and internal features, to a

very flexible representation where internal features are more pronounced and can be used across a range of transformations in the image. The model by Bruce and Young [Bruce, 86c] suggests, for familiar faces only, the formation and activation of FRUs that store abstract representations of an individual face. They proposed that, "A familiar face is represented via an interlinked set of expression independent structural codes for distinct head angles including with some codes reflecting the global configuration an others representing particular distinctive features." [Bruce, 86c]. Furthermore, Bruce and Young [Bruce, 86c] emphasized: "What is less clear at the moment is what description, or set of descriptions, of the face is necessary before recognition can occur." Unlike Marr [Marr, 82] who postulated an object-centred, three-dimensional model at this representation level, Bruce and Young [Bruce, 86c] postulate representations of distinct head angles that are linked in FRUs that do not have to be necessarily object-centred. This is because a single three-dimensional representation would not be suitable to cope with the fine discriminations required in face recognition within one class, where similar three-dimensional structures hold for all members of that class.2 Structural codes mediate the recognition of faces by activating its stored representations. FRUs theoretically become active after presentation of any recognizable view of a familiar face and are supposed to be view-independent [Burton, 94]. It depends on the activation level of the FRUsas to whether a face is recognized as familiar or not. People are very good at detecting familiar faces and rather poor at recognizing unfamiliar faces that were previously seen [Young, 86a] [Bentin, 88] [Hancock, 00]. Therefore, there should be no stored represen-tations or FRUs, respectively, for unfamiliar faces. Each face recognition unit contains stored structural codes that became elaborated through frequent exposure to a face. Exactly how the FRUs are established still remains unclear. Central to this thesis is the way in which facial information is represented and activated in

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[2] Bruyer & Galvez [Bruyer, 89] suggested that the ¾-views of face could constitute the structural code represented in FRUs because of several empiric results showing the ¾-view advantage with respect to a better performances when faces had been learned from that view or repeated in that view. However, as discussed by Bruce, Valentine & Baddeley [Bruce, 87b], no real support had been found for such an interpretation.

FRUs. The question is posed "Are representations of faces in memory viewpoint-dependent" and more precisely "Are FRUs viewpoint-dependent?" When an FRU is sufficiently activated it enables the subsequent access of semantic information. Bruce & Young [Bruce, 86c] separate the visually derived semantic code from the identity specific semantic code that exists uniquely for familiar people (e.g. their occupation). Visually derived semantic codes (e.g. gender or age) are already formed and help in remembering an unfamiliar face. Identity semantic information is stored in the so-called Person Identity Notes (PINs). The recall of identity semantic information resolves the feeling of knowing. The access to PINs can be facilitated via information from the FRUs or from the cognitive system directly. The latter can be described as a top-down process that causes activation of the FRUs in an indirect way, for example by invoking the person's name or occupation [Brunas-Wagstaff, 92]. Bruce and Young [Bruce, 86c] claim that semantic information stored in the PINs shaded into more general information associated with the specific information about a person. This associated knowledge is paraphrased by "cognitive system". After the retrieval of semantic information name recognition units (NRUs) can be activated. Semantic information is typically retrieved faster and more accurately than name information. The conclusion that name retrieval could occur exclusively via the PINs was challenged by Abdel Rahman, Sommer and Schweinberger [Abdel Rahman, 02]. Their findings support parallel and independent accounts of semantic access and retrieval rather than a serial process. Finally, the match between FRUs, PINs and a persons name give the feeling that a person has been successfully identified. Behavioural data, as well as neurophysiological findings, from priming studies as outlined in the following (see 1.2.2, 1.4.1.2) have provided empirical evidence to support the model by Bruce and Young [Bruce, 86c].

1.2.1.2 The IAC model by Burton et al. (1990) and options

1.2.1.2.1 Repetition priming and associative priming

The interactive activation and competition (IAC) model by Burton et al. [Burton, 90] and progresses by Burton and Bruce [Burton, 92] and Burton, Bruce and Hancock [Burton, 99] constitute an implementation of the face-identification components as postulated by Bruce and Young [Bruce, 86c]. The authors provide a basic principle for patterns of semantic priming and repetition (identity) priming, and decreased priming effects after image change and learning. It is a connectionist model and originates from "interactive activation

and competition models" by McClelland & Rummelhart [McClelland, 81]. By means of this model, various neuropsychological and empirical findings in normal and impaired face recognition [Burton, 91] could be simulated using threshold of information circulation that indices face recognition.

Priming in general means a change in the response to a stimulus (the target) due to a recent exposure to it or a similar stimulus and is used as a methodological tool to study the representational structure of different stimuli and faces in particular. In repetition priming a stimulus that is physically similar or identical to the preceding prime is used as a test stimulus. Because repetition priming depends on the match of perceptual factors between initial and subsequent presentation it is often referred to as identity, perceptual or recently as data driven [Boehm, 06a] [Boehm, 06b]. In semantic priming tasks the first and the second stimulus can be very different and even presented in different modalities (e.g. auditory-visual), but both share the same or an associated concept. Semantic priming, as well as associative or conceptual priming (or conceptually driven - Boehm, 06b; Boehm, 06a) benefit from semantic encoding and are often used synonymously. Still, semantic priming refers more to the category a stimulus belongs to, while associative priming is broader defined. Semantic priming is much more transient than repetition priming. Bruce and Valentine [Bruce, 86b] found reliable associative priming effects when related faces followed immediately, i.e. stimulus onset asynchrony (SOA) between 250 and 1000 ms, but did not persist beyond an SOA of 5s or when other faces intervened, effects vanished into insignificance Bruce [Bruce, 86a]. Repetition priming of face recognition has been shown to last for several months [Flude, 91] as cited in [Ellis, 92], despite contamination by the exposure to other faces in the meantime. Bruce, Carson, Burton & Kelly [Bruce, 98] found no difference in priming with a delay of on average two days. Priming can be explained by the so-called spreading activation models [Collins, 75] [McNamara, 92] [McNamara, 94]. These models take as their main idea that memory retrieval of an item activates its internal representation. This activation spreads throughout an interconnected network of memory traces (repetition and semantic priming) and therefore, the context in which that item occurs is activated as well (semantic priming). Residual activation accumulating at these memory traces facilitates subsequent retrieval. In reference to the IAC model by Burton et al. [Burton, 90], activation spreads through a network made of a number of pools of processing units. Five central pools of units are proposed (see *Figure*

2): one containing feature units, one containing FRUs, one containing Name recognition units (NRUs), one containing PINs and one containing semantic information (SIUs – semantic information units). The latter can be seen as what is meant by the information stored within the PINs and the cognitive system proposed by Bruce and Young [Bruce, 86c].

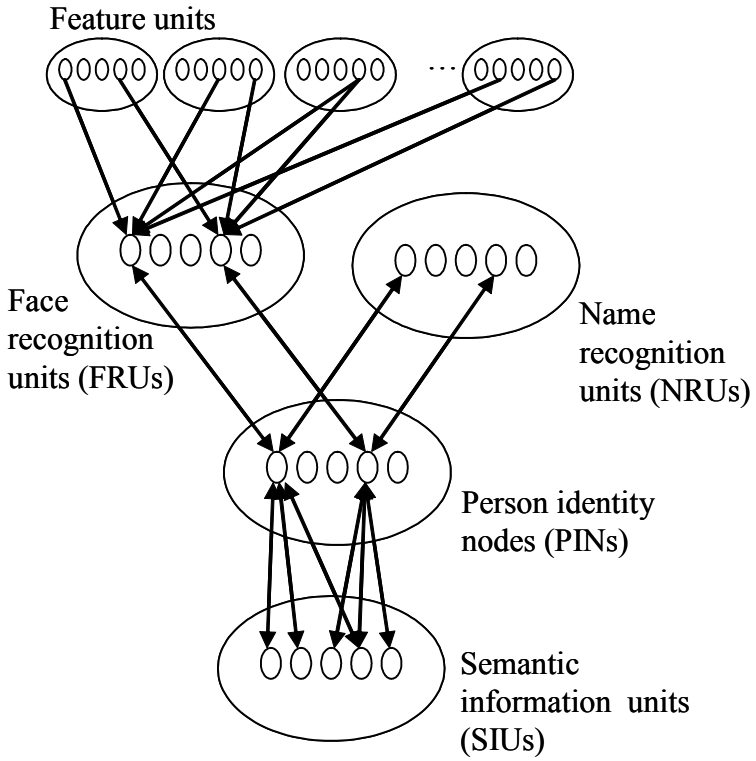

Figure 2: *Interactive activation and competition model by Burton et al. (1990)*

In the model introduced here, PINs form empty (without content) units that allow access to the semantic information stored in SIUs. Thus, PINs are the level of representation at which information from different stimulus types (e.g. faces, names) initially converge into a common representation. *Figure 2* shows bidirectional excitatory links between a person's FRU, and that person's PIN. Furthermore there are excitatory links between PINs and semantic information (SIUs) to that person that are bidirectional as well. There are inhibitory links within each pool. In the simulations all excitatory links and all inhibitory links have the same weight. But inhibitory connections are supposed to be weaker than excitatory ones. As distinct from the model of face recognition by Bruce &Young [Bruce, 86c] the decision about whether a person is familiar is made at a given threshold activation level at a PIN.

The process of face recognition is described as follows: FRUs receive their input from feature units that encode the visual features of a seen face. In terms of Bruce and Young [Bruce, 86c] feature units are at the level of expression-independent descriptions. If the face is a familiar one then the level of activation within the FRU for that face will rise above chance level and thus, above the activation of the other units. Then the face will be perceptually classified as familiar. If none of the FRUs respond significantly to a face, then it is regarded as unfamiliar. Name recognition units have a similar function in difference to FRUs they receive their inputs concerning written names. FRUs and NRUs pass activation to the PINs that represent a common pathway to semantic information stored in SIUs. If a face causes the activation level of a particular PIN to exceed a threshold, than that face is classified as familiar, having necessitated the prior activation of a FRU.
The mechanism for associative priming is ascribed to a spreading activation from prime to target PINs as semantic information units are linked to both PINs. The mechanism of repetition priming reflects a Hebbian-like strengthening of the excitatory connection between and FRU and the PIN when a person was previously identified. Once a PIN has achieved threshold activation this link becomes stronger. When a FRU is activated again the relevant PIN reaches threshold more quickly than before and to recognize a face requires less activation than before. The strengthening of FRU to PIN decreases to the base level slowly, which accounts for the longevity of repetition priming.
This is based on empirical findings that show that repetition priming depends critically on the match between study and test encounter. Priming is interrupted by a shift of modality or domain and thus cannot be explained on a semantic level as activation of the PINs or SIUs. For example prior exposure to famous people's names or body images does not facilitate the familiarity decision in a subsequent encounter of the related face [Bruce, 85] [Burton, 98] [Ellis, 87] [Ellis, 96a]. In contrast reading a famous person's name primes subsequent retrieval of that name but in response to later presentation of the corresponding face only. Ellis, Flude, Young and Burton. [Ellis, 96a] proposed that repetition priming of familiar faces occurs at two distinct loci. The first involves the perceptual recognition of a face as familiar and is domain-specific. Familiarity decisions made under time pressure are based on the perceptual familiarity or unfamiliarity of a face and do not require retrieval of semantic information. The locus of familiarity decision is at the level of PINs. Thus, repetition priming of familiarity decisions is domain specific [Burton, 98] [Ellis, 96a].

When a task demands a semantic decision that requires familiarity of the face (e.g. occupation, nationality) repetition priming is localized at the pre-semantic and the semantic level. The latter is the second locus of repetition priming. The retrieval of semantic information and / or the name is susceptible to both within- and cross-domain priming. A domain-shift will eliminate the repetition priming whereas the semantic part of the priming effect remains unaffected.[3]

The model by Burton et al. [Burton, 90] also accounts for effects of distinctiveness. Distinctiveness means that the familiarity of a face is rated more rapidly if the familiar faces have been rated as being more 'distinctive' rather than 'typical' [Valentine, 86]. To account for distinctiveness the input is entirely through features units. These features concern global measures of face shape, local measures of internal features as well as configural relationship of these features. At the level of feature units, individual faces do not share exact features with other faces, but they are similar to the extent that they share features, e.g nose, two eyes etc with other faces. PINs associated with distinctive faces reach threshold more quickly compared to PINs associated with typical faces, because the number of FRUs and FRU-PIN links activated at the same time decreases with the distinctiveness and increases with typicality of a face.

1.2.1.2.2 Perceptual learning and repetition priming across different images

An enhancement of the original model by Burton et al. [Burton, 90] accounts for perceptual learning of faces and is provided by Burton [Burton, 94]. The author discussed face learning as being mediated by the same process that underlies repetition priming. It is

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[3] The model by Burton et al. [Burton, 90] does not account for cross-domain priming (from faces to names) as found by Ellis et al. [Ellis, 96a] because name retrieval is not explicitly described. Burton & Bruce [Burton, 92] added name units to the pool of semantic information units in their model. Name units are abstract semantic representations corresponding to whole names. Following the activation of FRUs, information flows to PINs and from there the representations for biographical facts and names are activated simultaneously.

based on the assumption that faces are characterized as a set of features organised as feature units in feature pools. Feature pools and FRUs are linked. The initial state is represented by FRUs of already “known” faces receiving excitatory links from only one feature unit within a feature pool. There are “unknown” units in the FRU pool as well, each receiving connections from all features. An “unknown” face causes the excitation of a set of feature units that doesn’t correspond to a face already “known”. In this situation an unused unit in the FRU pool rises in activation. When the activation settled a Hebbian update function to all between-pool links as with the account of repetition priming is applied. This Hebbian update tends to associate a novel input pattern with a new FRU. Thus, perceptual learning of faces means that representations of “known” faces become established when the link is strengthened between feature units and new FRUs. IAC models account as well for repetition priming attenuation across different images and over some range of viewing conditions [Burton, 99]. Comparable to face learning the IAC model by Burton et al. [Burton, 90], as the cognitive part of familiar face recognition, is linked with a front-end feature analysis as the perceptual component. The front-end system is tied to the IAC through the FRUs. The perceptual front-end feature analysis is based on principal components analysis of face images. For a computer simulation 50 familiar faces are subjected to the PCA analysis. Every face had its own PCA input unit to the FRUs. Faces had been normalized with respect to shape and parameterized into 50 bits of information. Input to the model is through the PCA units. FRUs code the 50-component signature for each face. Different images had been realized in using different facial expressions. Consistent with human data, priming effects were attenuated when the image changed from the initial to the next encounter. Comparable to identical prime repetition, Burton et al. [Burton, 99] propose the following model: when a face is presented to the system (by means of the computerized IAC model) a number of FRUs are activated to differing degrees, though the correct FRU are activated the most. Similarly, the correct PIN gains most activation, though others may also gain a little. Different images of the same face cause slightly different patterns of activation in the FRU pool. Whereas identical face priming uses links that are already strengthened, faces primed by different images of the same face were strengthened only concerning the similarities between the two images. Despite having used different images with respect to expression, this model might account

for attenuated priming effects when images differ in view-point, when discrete viewpoints were represented separately.

1.2.1.3 FRUs and modularity in face recognition

In this thesis the model of Bruce and Young [Bruce, 86c] is used to generate hypotheses regarding the viewpoint-dependency of the facial representations stored in FRUs. Event related face potentials are related to different levels of face processing, especially dedicated to the activation of face storage units, namely the FRUs. The idea of modularity originates from the assumption that the cognitive system is composed of a collection of relatively independent processing components or modules, dedicated to perform a particular cognitive function [Chomsky, 80] [Fodor, 83] [Marr, 82] [Morton, 69]. Concerning the model by Bruce and Young [Bruce, 86c] modularity is closely connected to domain-specificity and refers to structural encoding and activation of FRUs providing the basis of identification. Following Nachson [Nachson, 95], face recognition is in a sense modular because it may take place on a pictorial and structural level as well as during the access of stored structural representations, in a separate, domain-specific system. Yet, domain-specificity itself is a controversially discussed issue (see 1.2.2.3). The notion of FRUs was derived from the recognition unit-metaphor, which has previously been used in theories of word recognition that describe "logogens" [Morton, 69] or object recognition assuming "pictogens" [Warren, 82]. It was suggested that each familiar word or picture has a separate stored representation activated when this word or picture is encountered. Proposed by Hay and Young [Hay, 82] and Bruce and Valentine [Bruce, 85], Bruce and Young [Bruce, 86c] modified the original analogy of "logogens" and "pictogens" and assumed within their functional model for face recognition special recognition units for faces. Like visual word recognition units and object recognition units FRUs store face-specific visual information, and contain representations dedicated to a specific stimulus class on a presemantic level [Ellis, 96b]. There is empirical evidence as well as neuropsychological findings that support the idea of modularity in face recognition and the idea of FRUs in particular. The finding that repetition priming is domain-specific whereas associative priming does cross domains, suggest different processing stages in face recognition [Bruce, 85] [Burton, 98] [Ellis, 87] [Ellis, 96a]. This is described, with reference to the IAC model by Burton et al [Burton, 90], in the previous chapter. Concerning repetition priming Bruce and Valentine [Bruce, 85] found that recognition of

familiar faces was facilitated by earlier presentation of the same picture and to a lesser extend by a different picture of the same person. This cannot be explained as a simple visual memory by match of the pictorial code, because Bruce and Valentine [Bruce, 85] also found an amount of priming when a different picture of the same face preceded, which was not correlated with the rated similarity between the two different pictures. This could be mediated by residual activation in face recognition units that responds when any view of a face is seen. Young et al. [Young, 86a] demonstrated that unfamiliar faces are only susceptible to priming when intervening items in an implicit recognition task had not separated prime and target. This reconciles the idea of FRUs as pools of stored representations that are available for familiar faces only. Beside evidence that comes from repetition priming neuro-psychological findings support the face recognition model by Bruce and Young [Bruce, 86c] namely dissociations between disorders of familiar and unfamiliar face recognition, disorders of face recognition and analysis of facial expressions, and the dissociation between facial speech analysis and other aspects of facial processing. This thesis will refer to the dissociation between the recognition of familiar and unfamiliar faces only, because it confirms the idea of FRU modules as pools of stored representations of an individual face. Bodamer [Bodamer, 47] introduced the term Prosopagnosia and was the first to highlight the selectivity of the disorder for faces. Prosopagnostic patients have an impaired ability to recognize faces, but remain able or relatively less impaired when recognizing common objects [Farah, 95a] [McNeil, 93]. Thus, they rely on other cues such as voice or typical gestures to identify familiar people. Following Hécaen [Hécaen, 81] at least two distinct types of Prosopagnosia can be described. Perceptual or apperceptive Prosopagnosia means the impairment of the ability to perceive faces in general. Mnestic or associative Prosopagnosia is characterized by the deficit to identify close friends or relatives by their face, while general face perception remains possible. Thus, different levels of severity seem to correspond to the levels of face processing [Sergent, 92b]. The apperceptive form can be described as the lack of structural encoding. The associative form can be seen as being due to either a disconnection of the structural codes of a face to the FRUs or the damage of the units itself. For all the arguments as outlined in the foregoing it makes sense to assume a modular system for the process of face recognition.

1.2.2 The neuroanatomical approach

1.2.2.1 The neuroanatomical model of face recognition (Haxby et al. 2000)

The neuroanatomical model of face recognition was introduced by Haxby et al. [Haxby, 00] and relates the functional components proposed by Bruce and Young [Bruce, 86c] to a distributed human neural system. The model supposes domain-specificity of the face processing in at least some neural structures (see 1.2.2.3). Cognitively distinct aspects of face perception are mediated by distinct neural representations. The system is comprised of multiple, bilateral regions representing both invariant aspects of a face that specify identity and changeable aspects of a face that facilitate social communication, such as eye gaze. This distinction is supported by behavioural studies that have shown identity to be independent from facial expression processing [Young, 86b] [Ellis, 90] and PET and fMRI studies [Sergent, 92a] [Hoffman, 00] and can be seen in *Figure 3*. The model is divided into a core system and an extended system. The extended system was recently modified by Gobbini & Haxby [Gobbini, 07] in that the role of the perception of facial expression, emotional response and the perception of personal traits and intentions associated with the extended system was specified. As the focus of this thesis is the core system, which was not modified in their later work, the following is still based on Haxby et al. [Haxby, 00].

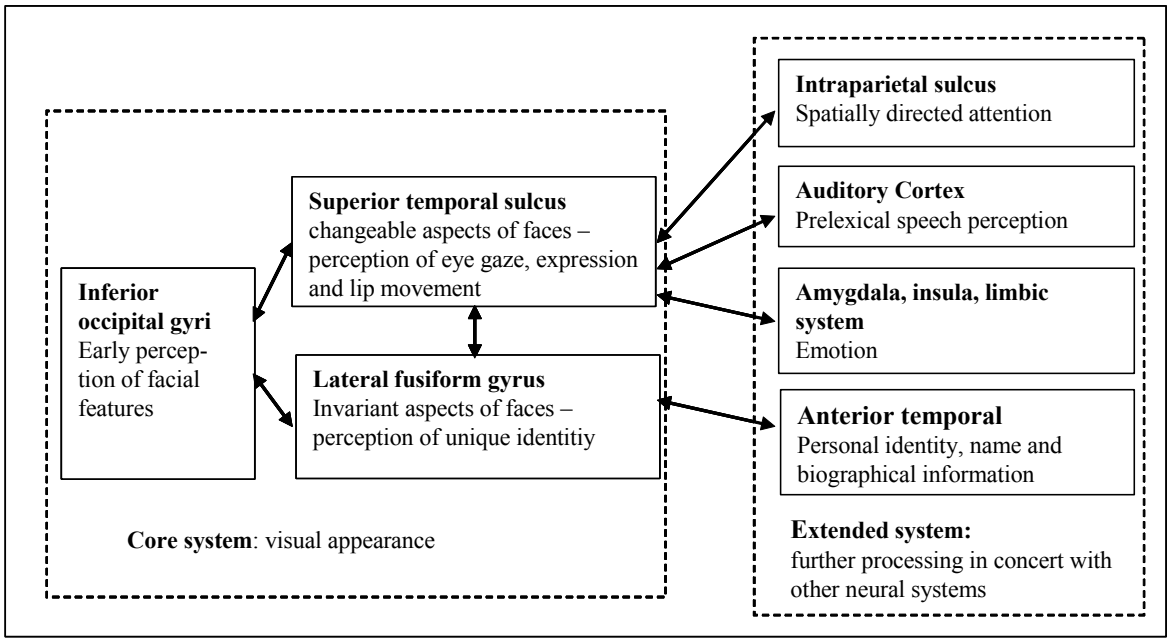


***Figure 3**: The distributed human neural system for face perception by Haxby et al. (2000)*

Facial information is processed by interactions within and between these subsystems. Neither assumption about the temporal sequence of their activation or interactions is established nor is the quantity of interactions shown by the figure exhaustive. Sensory information from the primary visual cortex reaches temporal and parietal lobes to form two relatively separate pathways. In the ventral or "what" pathway basic visual primitives are integrated into higher-level visual representations. Within the dorsal pathway the "where" and movement information is proceeded [Ungerleider, 82] [Ungerleider, 94]. In the neural system by Haxby et al. [Haxby, 00] the core system can be related to the ventral pathway and areas involved in spatially directed attention to faces might be a part of the dorsal pathway. The core of the system consists of three bilateral regions in occipitotemporal visual extrastriate cortex. These regions are in the inferior occipital gyri (IOG), the lateral fusiform gyrus and the superior temporal sulcus (STS). The region in the STS seems to represent changeable aspects of faces, such as eye and mouth movement and gaze direction [Ishai, 00] [Allison, 00] [Hoffman, 00]. The face selective activity in the IOG might be associated with the early visual processing of facial features or alternatively could reflect top-down modulations of these regions by the ventral temporal cortex [Ishai, 00]. For reasons of the anatomical location of the IOG, Haxby et al. [Haxby, 00] assumed that it provides input to the lateral fusiform as well as the superior temporal sulcal regions. A PET study by Rossion, Schiltz & Crommelinck [Rossion, 03b] revealed bilateral activation in the middle lateral fusiform gyrus within the fusiform face area (FFA) and the inferior occipital gyrus (here referred to as occipital face area, OFA) specific to face familiarity. Thus, the authors ascribe the FFA / OFA functions as discriminating between familiar or new and as categorising faces on a subordinate, individual level, reflecting an overlap between visual and pre-semantic mnestic representations. The region in the left fusiform cortex appears to be involved in the representation of the more invariant aspects of faces and thus, mediates facial identity [Eger, 05] [Rossion, 00a] see 1.2.2.2. Evidence for face selective activity in the fusiform gyrus was derived from fMRI studies. The perception of faces during passive viewing tasks [Kanwisher, 97] [McCarthy, 97] or tasks that focus attention on invariant aspects of the facial configuration like matching-to-sample tasks [Ishai, 99] [Ishai, 00], yielded pertinent data that suggest face specific activation in a region in the lateral fusiform gyrus. The activity found in this area is usually bilateral, but more consistently found on the right

side (see 1.1.2.2). As the activity in response to faces is greater than that evoked by nonsense stimuli or general objects this area, first named by Kanwisher et al. [Kanwisher, 97], has become known as the FFA. Furthermore, when tasks during fMRI focus on changeable aspects of faces, like eye gaze directions, the response in the FFA is reduced. That underlines the relationhip of face identity specific activity to that region [Hoffman, 00] and allows the connection to the activation of FRUs supposed by Bruce and Young [Bruce, 86c]. Recent studies have investigated response changes corresponding to different views of a face, the results are reported in 1.3.4. fMRI and PET offer relatively detailed localization of brain activity but with poor temporal resolution in the order of a few seconds. Therefore, they do not allow firm conclusions to be drawn about the sequence of activation, in the way that an ERP recording does.

Studies by Allison, Puce, Spencer and McCarthy [Allison, 99], McCarthy, Puce, Belger and Allison [McCarthy, 99] and Puce, Allison and McCarthy [Puce, 99] recorded the ERPs from the cortical surface directly, when such invasive recordings had been clinically indicated. Face specificity was evident during three latency windows from stimulus onset. Consistent with fMRI findings locations were clustered on the ventral occipito-temporal cortex and some were found on the posterior lateral surface of the temporal lobes. The earliest face specific component was a robust negative potential that peaked around 200 ms (N200). The second face specific component was a positive potential with an average peak around 350 ms (P350). This was also located in a face responsive region in the right anterior ventral temporal cortex. The last component was a slower and broader negative potential around 700 ms (N700). The results of these investigations are similar to those obtained in single cell recordings in monkeys. Compared with the face specificity of the single cells in monkeys, human N200 was more species selective to human faces [Bentin, 96].

Single-cell recordings of monkeys demonstrated the existence of cells in the temporal lobes that are tuned to respond selectively to monkey faces, but not to other complex visual stimuli [Perrett, 85] [Desimone, 91] [Logothetis, 96]. Face-selective cells were predominantly found in the patches of the cortex in the STS and in the inferior temporal sulcus. Hasselmo, Rolls and Baylis [Hasselmo, 89a] found dissociation between processes concerning expression and identity. Cells tuned differentially to expression had been found in the STS region and cells tuned to identity were found in inferior temporal cortex. The

STS seems to be mainly involved in the perception of facial movement and changeable aspects of a face. In primates as well in humans inferior temporal cortex appears to be involved in the perception of facial identity [Desimone, 84] [Young, 93]. This is in turn what Haxby et al. [Haxby, 00] described with the functional dissociation of the STS and the lateral fusiform gyrus concerning changeable aspects and identity specific, invariant aspects within the core system. Still, it should be kept in mind, that data characterizing the visual system of monkeys cannot be immediately generalized to humans.
The extended system is composed of regions apart from the visual extrastriate cortex. The perception of eye gaze direction causes activity in parietal regions associated with spatial attention. The model includes connections from the STS to the intraparietal cortex, which mediates directed spatially attention. Processes, such as lip-reading, elicit activity in regions that are associated with auditory processing of speech sounds. Facial expression is connected to the limbic regions, including the amygdala and insula, associated with the processing of emotion. Kreimann, Koch and Fried [Kreimann, 05] reported neurons even in the amygdala being selective to faces. Anterior temporal regions are associated with the activation of identity specific semantic knowledge. This level of processing is compatible with the activation of semantic knowledge stored in person identity nodes (PIN), supposed by Bruce and Young [Bruce, 86c].
Haxby et al. [Haxby, 00] introduced a neuroanatomical model specifically for face perception that is reconciled, as far as possible, with the model by Bruce and Young [Bruce, 86c]. The degree of separation between the functional roles taken by the different regions in this system, their interactions and temporal activation sequences remain unsolved questions. Despite the fMRI's power to reveal detailed functional neuro-anatomy of the ventral vision pathway, the neural correlates of face processing remain controversial.
Farah and Aguirre [Farah, 99] reviewed numerous PET and fMRI studies concerning their conclusions about the anatomical locations of visual recognition processing in the human brain. All studies used the coordinate system of Talairach & Tournoux [Talairach, 88] to report local maxima of activation. Despite that, the meta-analysis failed to find consistency, showing a wide range of locations. One proposed reason is individual differences in shape, meaning, that activations in the same locations are mapped to different locations in the "standard brain". Furthermore, the spatial normalization techniques themselves vary across laboratories. The authors conclude that analysis of

functional specialization requires imaging methods with a greater resolution and sensitivity that would allow for reliable within-subject comparisons.

1.2.2.2 Lateralized processes in face recognition

The early repetition effect (see 1.4.2.3), also referred to as ERE/N250r can be seen as a marker of FRU activation. Although, not a consistent picture, there is significant empirical evidence to show that this potential is more pronounced in the right hemisphere [Schweinberger, 02a] [Schweinberger, 02b] [Schweinberger, 04]. Lateralized activations as revealed by fMRI and PET studies can be assigned to different levels of processing in face recognition and were found to be dependent on familiarity and on the viewpoint of a seen face. Right hemispheric dominance was brought in line with processing of viewpoint-dependent rather than viewpoint-invariant aspects of a face like the processing of facial configuration. The following is to give an overview about empirical results concerning lateralization in face recognition. Results concerning lateralization on different levels of face processing and retrieval of view-independent aspects of a face will be outlined. In the first half of the 20th century commissurotomy was initiated for the treatment of severe intractable cases of epilepsy. Split-brain patients have undergone this treatment of disconnecting the right and the left hemisphere. Studies with these people gave information about lateralized cerebral functioning. Levy, Trevarthen and Sperry [Levy, 72] showed that split-brain patients centrally placed chimeric faces (each half from a different face) in a tachistoscope. All patients favoured the face represented on the left of the chimeric stimulus. As the left half field projects to the right hemisphere (and the right half field to the left), this indicates an asymmetry of function preferring the right hemisphere [Rhodes, 85].This was challenged by the finding that, in practically all cases that came to autopsy, pathological data revealed bilateral damage. Damasio et al. [Damasio, 86] concluded that face recognition is operated by both hemispheres, although each hemisphere recognizes and recalls faces with different strategies and that the right hemisphere was more efficient than the left. Computed tomography, fMRI and PET, have permitted the more precise study of many cases of prosopagnosia. Results are controversial, suggesting that prosopagnostics have either unilateral lesions in the left or right occipitotemporal region or bilateral lesions in this area. De Renzi et al. [De Renzi, 94] reviewed case studies investigating Prosopagnosia and found no manifestation of a dominance of the right temporo-occipital injuries. They suggest that a unilateral occipital damage is not sufficient

to produce Prosopagnosia, as it can be compensated by the healthy left hemisphere. On the other hand, Sergent & Signoret [Sergent, 92b] investigated three patients with unilateral damage in different cerebral structures of the right hemisphere. The damage caused a breakdown that involved different functional levels of face processing. Further contributions to the question about right hemispheric superiority in face recognition came from PET, fMRI and hemifield studies with normal, healthy subjects. Distinct neural systems for the recognition of faces had been found by Maguire, Christopher & Cipolotti [Maguire, 01]. They compared encoding and retrieval within and between different categories of stimuli like buildings, landscapes, human and animal faces. They found that the unilateral right fusiform gyrus was only activated during the retrieval of animal and human faces. The encoding of faces caused a bilateral activation of the fusiform gyrus. A second group of studies compared unfamiliar and familiar faces during encoding and retrieval. In general, predominantly right laterality of the FFA has been found in many studies using fMRI e.g. [Leveroni, 00] [Henson, 02] [Lehmann, 04]. Right cerebral hemisphere superiority for constructing facial representations was found in a study by Young, Hay and McWeeny [Young, 85a]. Behavioral data revealed that faces are identified more rapidly from the left visual field than from the right. Schweinberger and Sommer [Schweinberger, 91] tested right hemispheric dominance concerning stimulus encoding and memory within an ERP study. Using lateralized probe stimulus presentation the study revealed no hemispheric differences when stimuli are encoded, but a clear dominance of the right hemisphere when faces had to be memorized. Similar results had been found by Yovel, Levy, Grabowecky and Paller [Yovel, 03]. Left visual superiority was reflected in different stages of face processing, manifested in ERPs from 170ms after stimulus presentation. The authors proposed that there is an asymmetrical exchange of facial information between the two hemispheres from the early stages onwards. Bernstein, Beig, Siegenthaler and Grady [Bernstein, 02] tested the difference of encoding and recognition of unfamiliar faces after different encoding strategies had been applied. fMRI revealed differences between encoding and recognition irrespective of the encoding strategy. Only during recognition was a primarily dorsal set of regions, including right prefrontal and parietal areas, activated. Encoding activated a ventral system including bilateral and temporal and fusiform regions and left prefrontal cortices. Comparable results have been also found in a recent study by Tsukiura, Mochizuki-Kawai and Fujii [Tsukiura,

05]. During fMRI after encoding, subjects participated in the retrieval task of people's names from faces and people's faces from names. The left anterior temporal lobe was significantly activated during the retrieval of people's names from faces, whereas the right anterior temporal lobe was activated during the retrieval of people's faces from names. Interhemispheric cooperation was investigated by Mohr, Landgrebe and Schweinberger [Mohr, 02]. In a hemi- field study only familiar faces profited when presented on both visual hemifields. Unfamiliar face processing did not yield a bilateral advantage. PET studies by Rossion, Schiltz, Robaye, Pirenne and Crommelinck [Rossion, 01] and Rossion, et al. [Rossion, 03b] only revealed larger activation in the right fusiform gyrus and right inferior occipital cortex for unfamiliar faces. This they attributed to a categorization process at a familiar-unfamiliar level on the basis of visual representations that overlap pre-semantic mnestic representations of faces in the right hemisphere. Investigating encoding and retrieval in terms of episodic memory some studies found right prefrontal activity for retrieval tasks and left prefrontal activity for encoding tasks. This was summarized by Tulving, Kapur, Craik, Moskovitch & Houle [Tulving, 94] with hemispheric encoding and retrieval asymmetry (HERA) and could be replicated especially for face stimuli by Haxby et al. [Haxby, 96]. However, there are fMRI studies showing activity in right prefrontal areas mainly for both encoding and retrieval of face stimuli [Okada, 00]. Concerning lateralization of viewpoint-dependent processes in face recognition Rossion et al. [Rossion, 00a] specified the role of the left and right middle fusiform gyrus. Increased activation was found in the right middle fusiform gyrus when matching whole faces than face parts individually, whereas its left hemisphere homologue is involved in matching face parts. This pattern of lateralized differences was face-specific and emphasizes the importance of configural face processing at least in the right hemisphere. A similar result yielded Iidaka et al. [Iidaka, 03] in a fMRI study by investigating the left and right hippocampus region when recognizing newly learned faces. Pourtois, Schwartz, Seghier, Lazeyras & Vuilleumier [Pourtois, 05] demonstrated hemispheric differences when faces had to be recognized across different viewpoints. Using fMRI and a long-term repetition priming paradigm identity traces had been found in both hemispheres, but these are partly view-dependent and show only a limited generalization to different views. Instead a distinct region in the left middle temporal and the left inferior frontal cortex can maintain viewpoint-invariant traces for the same faces.

This was brought in line with later processing stages, such as the retrieval of semantic information, rather than early perceptual stages that are subserved by the FFAs. The degree of image dependency across the fusiform cortex was investigated by Eger et al. [Eger, 05]. Their study showed a greater image dependency in the right, rather than the left fusiform cortex. Moreover, there was a greater generalization of repetition priming effects across changes in viewpoint for familiar faces in the left anterior fusiform region, reflecting its role of coding image-independent representations of familiar faces. A study by Burgund and Marsolek [Burgund, 00] demonstrated similar differences between the left and the right hemisphere in object recognition. A Participant was asked to name either the same or a different view of objects presented briefly to the left or the right visual field. Viewpoint-dependent priming was observed when test views were presented directly to the right hemisphere, but not when test views were presented directly to the left hemisphere. The authors concluded that there are dissociable neural subsystems, one in the right hemisphere storing objects in a viewpoint-dependent manner and another in the left storing viewpoint-invariant aspects of an object.

To summarize, lateralized processes seem to involve structural encoding as well as the retrieval of the stored representations. However retrieval is mainly reflected by a predominant activation in the right hemisphere, especially concerning configural and view-dependent aspects of a face. Retrieval of more view-independent aspects of a face, for example facial parts, seems to be lateralized in the left fusiform region.

1.2.2.3 Domain specificity in face recognition? – An Excursus

As outlined in 1.3 the discussion about viewpoint dependence versus independence in face recognition is largely based on findings in object recognition. Still, there is a controversial discussion about domain specificity in face recognition that refers to the question of whether face recognition is different from recognition of objects or words with respect to the stimulus class itself and to neuroanatomical issues. The use of the term ‘domain’ goes back to Baddeley [Baddeley, 82] referring to stimuli that are processed to some extent by specialized recognition systems. Investigating the facial representations with respect to their viewpoint-dependency, in this thesis, faces are regarded as a special object class, which is highly differentiated. The following is to give a better understanding of that point of view. A PET study demonstrated face selective activation patterns in the lateral

posterior fusiform gyrus, similar to the adult face-processing network, even in two month old infants [Tzourio-Mazoyer, 02] when unknown femal faces are recognized. Despite existing differences between two-month-old infants and the brain anatomy of an adult, the anatomical location of the inferior temporo-occipital activation focus found in infants was close to the FFA [Kanwisher, 97]. This result illustrates the specificity of face perception per se, but says less about the way in which face recognition per se is special. The question of whether face recognition, from early childhood, is a product of biology, expertise or both is intensively discussed in cognitive neuroscience. Faces are inimitably complex. Identification of a face within a class of faces relies on the detection of subtle featural and configural differences. It means the recognition of physiog-nomic variants of a given face from different representations in terms of expression or angle of view. Reliable face recognition needs years of experience. Bruce and Valentine [Bruce, 85] refer to Rosch [Rosch, 76], who used the term "basic level" categories for broad object classes (tables, houses, dogs) and define faces as a "basic level" category themselves. Unlike objects to identify a face is to discriminate within this rather homogeneous category: "When we consider face recognition, and the hypothesis of face recognition units in particular, we are talking not at a basic level of categorization, but at the level of familiar instances. Each face recognition unit must respond only to a particular individual." ([Bruce, 85] p. 382). Bruce & Humphreys [Bruce, 94] suggest that if the recognition of objects begins to make similar demands to face recognition, as discrimination within a set of items sharing the same shape and as observers acquire expertise with non-face objects, processes involved appear more similar for objects and faces. Thus, when object and face recognition are compared the category level has to be taken into account (e.g. a more fine-grained subordinate specific-level for one object class). Additionally the authors see differences concerning pictorial and structural encoding that distinguish object from face recognition in the basic-level category. The identification of objects depends on edge coding, whereas face recognition depends more on representation of surface properties such as color and shading. Furthermore object recognition seems to involve part-based descriptions and face recognition depends more on holistic processing [Tanaka, 93] [Farah, 98]. Evidence for and against the specificity of face recognition is derived from studies with prosopagnositic patients, the special effects related to the recognition of inverted faces, the cerebral blood flow response (PET, fMRI) and of the specificity of electrophysiological data (ERPs).

Empirical results of domain specificity concerning electrophysiological correlates of face processing are outlined when ERP components are described in detail in 1.4.2. Initial, strong evidence came from patients suffering from acquired or developmental Prosopgnosia [Barton, 03] [DeHaan, 99].[4] Clinical observations show "double dissociations" of object agnosia without Prosopagnosia without object agnosia indicating different brain loci for object and face recognition [Damasio, 82] [Sergent, 92b] [McNeil, 93] [Farah, 95a] [Duchaine, 05]. Neuner & Schweinberger [Neuner, 99] determined the dissociability of face, voice and personal name recognition and naming. Their results are consistent with the assumption that impairments in face, voice and name recognition are dissociable with one another, whereas face and voice naming could not be clearly separated. Still, Plaut [Plaut, 95] observed that behavioral dissociations would not indicate domain-specificity and modularity in recognition processes, where each module is dedicated to perform a different task. Investigating the effects of double dissociation between concrete and abstract word reading after brain damage in a connectionist network, he concludes that double dissociations refer to different degrees of specialization within the same system. This is in line with the idea of basic-level categories, such as objects and faces. Object agnosia constitute a between category breakdown whereas Prosopagnosia is related to a within category breakdown. The face inversion effect has been a strong argument for the specificity in face recognition, at least for its sensitivity to holistic aspects that are realized mainly in the upright orientation. Yin [Yin, 69] found that upside-down faces are disproportionately more difficult to recognize than other inverted objects. The so-called "Thatcher illusion" demonstrated first by Thompson [Thompson, 80] provides more evidence that face recognition is a highly specialized process depending on the spatial relations among features. In a photograph of Margaret Thatcher, the eyes and mouth had been rotated 180° within the facial context. This alternation might produce a change in

[4] Developmental prosopagnosia is present from early childhood on. A neurological anamnesis is not to be found, but for some cases a family factor has been reported, indicating a genetic predisposition of face recognition. Acquired Prosopagnosia describes a specific impairment in face recognition caused by localized brain damage.

spatial relationship. When the whole face is additionally turn upside down this is almost imperceptable. This shows that face recognition relies on holistic or configural properties compared to rather part-based object recognition, at least when the face is presented upright. Farah et al. [Farah, 95b] found that prosopagnostics handled inverted face stimuli with the same or even better capability as normal controls. Inverted faces are handled rather like objects und thus should be reflected in less activity in the extrastriate face-responsive regions and a shift of activity towards the region responding prior to objects. Three studies contradict this hypothesis. Haxby et al. [Haxby, 99], Kanwisher, Tong and Nakayama [Kanwisher, 98] and Aguirre, Singh and D'Esposito [Aguirre, 99] found that the failure of face perception systems with inverted faces leads to the recruitment of processing resources in object perception systems, whereas activity in face selective regions is not affected by face inversion. Furthermore Diamond and Carey [Diamond, 86] show that the inversion effect is not specific to faces. They found that that a dog expert's ability to identify an individual dog of the same breed is disrupted by inversion, as is human face recognition.

Studies investigating cerebral blood flow response in using fMRI or PET in the intact and in the damaged human brain lead to three distinct assumptions for the functional architecture in ventral temporal cortex are a cause of controversial discussion. The first assumption, that the underlying neural structures devoted to face, object or word perception are also exclusively dedicated to these processes, is represented by Kanwisher and colleagues e.g. [Kanwisher, 97] [Kanwisher, 00] [McKone, 07]. Their arguments concentrate on the FFA that shows an activity four times as high than that measured during discrimination of e.g. hands or objects [Rhodes, 04]. According to these authors, the FFA neurons are a priori tuned for individuating faces. Supporting evidence (see 1.2.2.2) came from studies that found a right hemispheric dominance in the processing of faces compared to flowers [McCarthy, 97], buildings [Gorno-Tempini, 01], words [Kim, 99] and names [Pfütze, 02]. Liu, Harris and Kanwisher [Liu, 02b] used magneto-encephalography (MEG) to investigate stages of processing in face recognition. In this experiment subjects matched front view test images of faces and houses to profile views (faces) and three quarter views (houses). They found face-selective MEG response occurring 100 ms after stimulus onset that was correlated with successful classification of faces. A second MEG response after 170 ms was associated with classification as well as individuation of a face. A study by

Grill-Spector, Knouf and Kanwisher [Grill-Spector, 04] compared within the category identification of faces and objects using fMRI. The results suggest specialized FFA activation when faces are recognized and identified. Non-face stimuli activation was correlated with other regions of the ventral temporal cortex. Still, it is difficult to find a comparable fine-grained object categorization or a within categorization natural to faces, and hence, to interpret the results as really stimulus-specific activation pattern.
In contrast to the domain-specific hypothesis Gauthier and Tarr [Gauthier, 00c] postulate that the face selectivity of the FFA reflects a more generalized form of processing not intrinsically specific to faces (for overview see Bukach, Gauthier & Tarr, [Bukach, 06]). Several neuroimaging studies in humans [Gauthier, 99b] [Gauthier, 00b] and monkeys [Gauthier, 00a] indicate that the level of categorization and expertise interact to produce the specialization for faces in the FFA. In human studies acquisition with novel objects (Greebles) led to increased activation in the right hemisphere face areas [Gauthier, 99a] [Gauthier, 99b]. Greebles resemble faces in the level of specialisation of configural information within a homogenous Greeble class while sharing the same basic features and configuration. Thus, when Greebles are studied the sensitivity to configural differences is trained to identify a Greeble [Gauthier, 97]. Even when other homogenous categories had been tested like cars or birds, an increase in activation in the FFA region could be found related to homogeneity of a class rather than familiarity of a class [Gauthier, 00c] [Gauthier, 02b] [Xu, 05]. However, Tanaka [Tanaka, 01a] noted two differences between object and face expertise. First, object expertise is a specialized activity achieved by explicit training and by a few people only. Second, subordinate levels in object recognition correspond to different levels in abstraction compared to the individuation when faces are recognized.

Evidence contrary to Gauthier and colleagues was demonstrated by Duchaine, Dingle, Butterworth and Nakayama [Duchaine, 04]. Using a design almost identical to Gauthier and Tarr [Gauthier, 02b] for learning of 20 different Greeble individuals, a male patient suffering from associative Prosopagnosia from childhood on was able to perform the learning session comparable to control subjects who did not show face recognition impairments. This is clearly inconsistent with the assumption that Prosopagnosia is caused by a deficit to domain-general expertise mechanisms that are engaged after only hours of training.

The third view proposes that the representation of faces and different categories of objects are widely distributed and overlapping [Haxby, 01]. Each category elicits a distinct pattern of response in the ventral temporal cortex that is also evident to a variable degree for a different category. One category can be distinguished by a special pattern of activation. Evidence comes from studies by Chao, Martin and Haxby [Chao, 99] and Ishai, Ungerleider, Martin, Schouten and Haxby [Ishai, 99]. Haxby et al. [Haxby, 01] propose the term "object form topography" for the topographic organization of the distributed representation of faces and objects within the ventral temporal cortex.
In summary, it is not yet clear whether the putative face-processing system is the product of biology, expertise or both. Still it is clear that faces are unique in the sense of homology within this category, making fine-grained analysis of configuration and features essential. Therefore, face recognition in this thesis is considered as an outstanding singular case of object recognition.

1.3 Viewpoint-invariance or viewpoint-dependence of facial representations in memory?

How are facial images stored in memory to enable face recognition that is reliable despite changes in viewpoint even if it requires recognition from an unfamiliar viewpoint? Does the human brain represent faces for recognition in a viewpoint-dependent way by storing a series of two-dimensional snapshots or are the face models viewpoint-invariant three-dimensional analogs of the faces they represent?
Viewpoint-dependent coding, because it is affected by the position of the viewer relative to the object or face being recognized, can be described as viewer-centred. A viewer-centred description of an object or a face is specific to the particular viewpoint from which the object or the face is seen. Separate viewer-centred representations are needed to enable recognition of the object from different views. Such coding poses the problem that different views of a particular object would have to be treated as separate objects. Learning associations between one view of an object or face and its features would not enable the retrieval of these features when a different view of the object or face is encountered. These problems are avoided using a viewpoint-invariant representational system. Under this, system features of the object or face are related not to the viewer but mainly to the object itself (e.g. the longest axis) and thus, can be described as object-centred. Although the appearance of features of an object changes relative to the viewer when the angle of view

is changed, their orientation relative to a point of reference on the object itself remains constant. Theoretically only one object-centred description of an object would have to be coded for recognition to be possible from any view.
The following theories make different assumptions about viewpoint-dependence according to the category-level and the angle of view-change which view-independence is expected for. Viewpoint-dependence as marked by performance (e.g. reaction time and accuracy) in a recognition task is modified by a complex interaction of the similarity of the stimulus class by means of the category-level and by expertise e.g.[Gauthier, 99a]. In general there is a continuum of viewpoint-dependence to almost complete viewpoint-invariance corresponding to the continuum from basic-level category like faces per se to subordinate (special) -level category [Tarr, 03] like Ms. Smith and Ms. Miller from next door. The more homogenous the stimuli are the greater viewpoint-dependency. This was found across a wide range of stimuli and tasks, with common objects [Jolicoeur, 85], novel two-dimensional [Tarr, 89] and three-dimensional objects [Bülthoff, 92] [Biederman, 93] [Hayward, 00] and especially faces e.g. [Hill, 97] [Troje, 96]. Expertise with a stimulus class supports recognition performance towards viewpoint-independence e.g. [Schyns, 93].
In the following sections theories of object representations in memory are described, specified by modifications for face recognition and completed by empirical results. Finally, a conclusion is drawn with respect to the objective in this thesis.

1.3.1 Theories that rely on three-dimensional representations

1.3.1.1 Recognition by components (RBC) Biederman (1987)

Following Biedermann & Gerhardstein ([Biederman, 93] p. 1163) viewpoint-invariance is defined as absence of an effect of orientation disparity between two images. If so, that would indicate that face recognition relies on object-centred representations that are invariant to changes in viewing conditions and therefore can be described as three-dimensional.
Biederman [Biederman, 87] and Marr and Nishihara [Marr, 78] hypothesized that representations of objects in LTM code, features in a part-based manner that is independent of orientation and thus, stable across changes in viewpoint. Objects were drawings of three dimensional basic-level or “entry-level” categories like pianos, chairs, aeroplanes, torches and nonsense objects [Biederman, 91] [Biederman, 93], comparable to Greebles but with sharp edges [Gauthier, 98]. Biederman’s [Biederman, 87] “recognition-by-components”

(RBC) or “Geon” theory postulates that depth invariance or object consistency can be achieved and in fact derived from a single view of an object, illustrating immediate viewpoint-invariance. Incoming stimuli are represented as structural descriptions that specify the three-dimensional structural relations among viewpoint-invariant geometric primitives, namely geons. Geons are defined by using non-accidental properties [Lowe, 85] that are, at least for a certain range of views, meant to be viewpoint-independent. Thus, object consistency is part-based and for that reason immediately achievable. As long as two views activate the same geon structural description (GSD), viewpoint-invariance is expected and thus achieved by a single view. No systematic effect of orientation on reaction time or error rates for both, familiar and novel test views is predicted [Biederman, 93]. Immediate viewpoint-invariance would not be expected unless the following three conditions are satisfied: First, an object has to be decomposable into viewpoint-invariant parts. This is not the case for highly irregular objects, for instance, crumbled paper. Second, highly homogenous stimuli classes would not achieve object constancy, because geons on a subordinate level are too similar. This point is critical for face recognition based on representations on a subordinate level. Third, when rotation causes accretion or deletion of geons, viewpoint-invariance is no longer expected. Therefore, an extreme orientation disparity, e.g. from frontal to profile view (90°), within a class of similar (“Caucasian”) face stimuli, would not meet the conditions to achieve viewpoint-invariance as immediate viewpoint-invariant recognition is expected for limited points of view and basic-category levels only. A more recent approach to viewpoint-invariant recognition of faces and objects is the research into recognition by invariant and extended features by Ullman & Bart [Ullman, 04]. The authors simulated recognition ranging from frontal to 60° profile view. Similar to Biederman [Biederman, 87] the idea is that viewpoint-invariance is obtained from the viewpoint-invariance of simpler components that are common to multiple objects within a general object-class, like faces. Extended features are generated by a set of appearances of a component under different viewing conditions, without using three-dimensional information. A principle for their extraction of a single appearance is suggested by Ullman, Vidal-Naquet and Sali [Ullman, 02] and will not be outlined in detail here. Following a learning stage the computer system was able to identify multiple known components in a novel object view. Although, less able to account exclusively for the demands of face recognition, as faces are processed in a configural manner as well, the

idea of feature extraction that are invariant across view changes from a single point of view, must be kept in mind. Support for the use of facial parts in recognition of faces comes from primate studies that have shown neurons in the temporal cortical visual areas of the macaque that especially responded to facial parts ([Perrett, 82] see [Rolls, 00] for a review). Still, for the special case of face recognition Biederman and Kalocsai [Biederman, 98] pointed out that face recognition is not based on parts primarily as it is most notably a holistic process (see 1.3.2.1). Thus the results revealing viewpoint-invariance with respect to response accuracy for familiar [Patterson, 77] [Bruce, 82] and unfamiliar [Davies, 78] faces and response latency [Roberts, 89] might be caused by factors other than by a process that only decomposes a face into its three-dimensional parts.

1.3.1.2 Recognition by alignment (Ullman, 1989)

An alternative approach to the recognition by part-based representations, as introduced above, is the recognition of image-based representations by alignment [Lowe, 85] [Ullman, 89]. Following the alignment approach, recognition is performed by bringing an internal three-dimensional model into alignment with the observed image. Initially, the transformation in space is determined that is required to bring the viewed object into alignment with possible object models (alignment stage). In the second stage the model that fits best with the currently seen object is determined (matching stage). Whereas in the first stage the search is through all the possible views, in the second stage the search is through the possible object models. Ullman [Ullman, 89] distinguishes between a full alignment scheme that attempts to compensate for all possible three-dimensional transformations and a partial alignment scheme. In the latter, objects are decomposed by pictorial descriptions. The partial alignment scheme uses multiple views to compensate for three-dimensional transformations. Thus, Ullman [Ullman, 89] supposed recognition to be both, “view-dependent, since a number of different models of the same object from different viewing positions will be used” and “view-insensitive, since the differences between views are partially compensated by the alignment process” ([Ullman, 89] p. 228). As the complexity of the alignment is correlated to the range of transformation, viewpoint-dependent patterns are predicted for reaction times while viewpoint-invariant performance is predicted for error rates. To sum up the alignment approach, it is difficult to extract sufficiently accurate three-dimensional models that allow reliable discrimination between similar objects which would account for discrimination of objects on a basic-level

[Ullman, 04]. For the within class discrimination on a subordinate-level Moses, Ullman and Edelman [Moses, 96] suggest that in the case of face recognition different face images are stored in an interdependent (rather than independent) manner to extract information about the three-dimensional shape of a face. This resembles Bruce and Youngs [Bruce, 86c] notion of the FRUs. Since in their experiments only a single image was available in the learning phase and generalization performance was found to be over 97% correct even in the largest angular separation (51°) independent storage of images could be ruled out [Moses, 96]. O'Toole et al. [O'Toole, 98] assume that view alignments are done to at least a subset of canonical views (see 1.3.2) as a face-specific process. Still, the aligning as referred to O'Toole et al. [O'Toole, 98] means transforming a view of a face into a learned view in the sense of a two-dimensional model rather than a three-dimensional model as assumed by Ullman [Ullman, 89]. After that an interpolation process is assumed for the recognition of a given face as known or unknown (see 1.3.2.1.3).

1.3.2 Theories that rely on two-dimensional representations

There is psycho-physiological evidence that objects are represented by a series of two-dimensional images rather than three-dimensional parts by the phenomenon of canonical views e.g. [Edelman, 92] [Schendan, 03] and limited generalization from one view to another e.g. [Edelman, 92] [Logothetis, 96]. Reaction times and error rates were found to be dependent monotonically on the disorientation of the test view relative to the stored views. Tarr, Williams, Hayward and Gauthier [Tarr, 98c] tested the recognition-by-components-theory [Biederman, 87] directly. Geons (e.g. brick, claw, cylinder) had to be recognized under changes in viewpoint. The authors found robust viewpoint effects in these extreme simple three-dimensional volumes. Even after extensive practice of many different views a difference in reaction times and error rates still existed, although smaller e.g. [Bülthoff, 92] [Edelman, 92] [Tarr, 89]. Another argument supporting image-based theories is the finding by Palmer, Rosch and Chase [Palmer, 81]. They argue that humans consistently labeled certain views as "better" than random views. In a naming task subjects tended to respond quicker when the stimulus was shown from a good or canonical, e.g. ¾ perspective. Reaction times increased with deviance from the canonical view. The ¾-view is especially interesting because it reveals the most useful features for identity recovery, or gives the best representation of the three-dimensional shape of a face. With reference to this property of the ¾-view two types of effects can be identified in the literature. The

different view advantage shows that faces learned or tested in a ¾-view may generalize better to other views e.g. [Bruce, 87b] [O'Toole, 98] [Patterson, 77] [Pourtois, 05] [Troje, 96] [Schyns, 93]. The same view advantage shows that faces in ¾-view are better identified than other views when the training and the test views are identical e.g. [Bruce, 87b] [O'Toole, 98]. Still, other studies suggest that face recognition performance is not necessarily facilitated when the face is shown in ¾-view [Hill, 97] [Liu, 02a]. Since the authors have not found a ¾-view effect in terms of generalization, or in terms of the same view advantage, Liu and Chauduri [Liu, 02a] suggest that a better predictor for recognition in different views is the angular difference between learning and test views.. Hill et al. [Hill, 97] only found a peak in performance when the opposite ¾-view was to be recognized. The ¾-view effect stands as an argument in favor of image-based rather than part-based recognition. All of the theories below have in common an attempt to achieve viewpoint- independence on a subordinate-level by means of face recognition within this stimulus class by storing multiple two-dimensional viewpoint-specific representations, in the sense of image-based views. To provide reliable recognition across view-changes, a previous encounter of more than a single view is postulated.

1.3.2.1 Fiducial points (Wiskott, Fellous Krüger & von der Marlsburg, 1996)

Biederman and Kalocsai ([Biederman, 98] p. 1203) point out that face recognition, as opposed to object recognition, cannot be understood by RBC theory because "... individuation of faces requires specification of the metric variation in a holistic and integral representation of the facial surface." Thus the information that entails face recognition is rather image-based than part-based, discontinuous and non-accidental like information that is used for recognizing objects. In a matching to sample task Kalocsai, Biederman and Cooper [Kalocsai, 94] found increased reaction times and decreased accuracy when faces had been rotated stepwise from -20° to 40° to the left. The authors concluded viewpoint-dependency in face recognition and linked that to a model of face recognition as introduced by C. von der Marlsburg and associates [Wiskott, 96]. Based on a two layer network developed by Lades et al. [Lades, 93], Wiskott et al. [Wiskott, 96] introduced a system for recognizing human faces from single images out of a large database of different faces. During recognition the pattern of activation of the input layer is mapped onto a representation layer. Within these layers faces are characterized by fiducial points, such as the corner of the eye and mouth or the tip of the nose and the edges or

distances between them. The edges are labeled by two-dimensional vectors. Concise face descriptions in reference to each fiducial point are extracted and form an image graph that individualizes a face. Within the image graph fiducial points are connected to each other. In that sense the method is not based on the construction of a three-dimensional model of the face rather than feature vectors and that are transformed with rotations in depth. Thus, viewpoint-invariance is limited. Recognition is based on comparison of image graphs with an incoming face, yet it is still possible over a small range of viewpoint changes (21°).
Following Biederman and Kalocsai ([Biederman, 98] p. 16) "in terms of a current psychological theory of face recognition, the two layer network would be an alternative to Bruce's Face recognition units (FRUs)". Still, while FRUs are supposed to be viewpoint-independent (Burton, 1994) the network provides only restricted capabilities to generalize over large rotations in viewpoint and thus viewpoint-invariance for a limited range of viewpoints.

1.3.2.2 Multiple-views-plus-transformation (MVPT) theory by Tarr & Pinker (1989)

MVPT [Tarr, 89] postulates that objects are represented as linked collections of viewpoint specific two-dimensional images each corresponding to a different orientation. Novel orientations of the same stimulus are recognized when they activate the set of views that is related to a familiar object. Empirical results support the idea of multiple views revealing an increase of reaction times or decrease of accuracy in relation to viewpoint change [Bruce, 87b] [Krouse, 81] [Troje, 96]. Wallis and Bülthoff [Wallis, 01] demonstrated the influence of spatiotemporal association on the recognition of faces. Participants were shown sequences of novel faces in which the identity of a face changed as the head rotated. Observers showed a tendency to treat the views as if they were of the same person. Only the spatiotemporal relationship linked the recognition from the first to the second encounter, not the identity itself. When faces would be stored as three-dimensional entities the identity switch must have been realized by the observers. Moreover, the results suggest a continuous association of views to support later recognition on the basis of appearance in time and physical similarities.
Practice with multiple orientations diminishes viewpoint-dependency. Schyns & Bülthoff [Schyns, 93] did not found a reduction of performance from the first to the second encounter when any view was learned comparing to just one learned view, what might be

due to the integration of multiple views by view-interpolation into a single viewpoint-independent representation caused by an increase of familiarity with a specific face [Bülthoff, 95]. Thus viewpoint-invariance might be achieved [Eger, 05] [Patterson, 77] [Roberts, 89], which could be interpreted as a change from a two- to a three-dimensional system. Critically, performance for unfamiliar views remained viewpoint-dependent, which supports the multiple-view theory e.g. [O'Toole, 98] [Troje, 96]. Moreover even the recognition of ones own face seen from the profile is slower compared to the frontal view. In this respect the recognition of one's own face is performed in a similar way to recognizing a face with which one is not familiar [Troje, 99].
The following theories can be considered as variants of the empirically based MVPT theory by Tarr & Pinker [Tarr, 89]. Importantly, all theories share the assumption that at least two learning views of a face were essential to be able to recognize the face from an unfamiliar point of view. The mechanism through which an incoming stimulus is matched to the stored representations varies among the theories and is outlined below.

1.3.2.2.1 Mental rotation (Shepard & Metzler, 1971; Tarr & Pinker, 1989)

One mechanism to cope with orientation changes of a stimulus was thought to be mental rotation. The new orientation of the input is transformed to one of the stored orientations by mental rotation either to one at the nearest orientation or one at a canonical orientation ([Tarr, 89] p. 233). Mental rotation was first described by Shepard and Metzler [Shepard, 71] and experimentally tested by Shepard and Cooper [Shepard, 82] using three-dimensional block drawings and two-dimensional random polygons. Mental rotation was explained as mental analogs of actual physical transformations and is a time consuming process that causes an increase in reaction time proportionally related to the range of disparity from previously trained orientations. An effect on error rates is not predicted, because the input can be transformed into an optimal configuration prior to comparing it to one of the stored views (for review see [Bülthoff, 95]). Valentine and Bruce (1988) investigated effects of rotation of faces away from the vertical. They found a linear relationship between reaction times and the angle of rotation in plane and brought this in line with the notion of mental rotation by Shepard and Metzler [Shepard, 71]. Using ERPs Schendan & Kutas [Schendan, 03] described a late (420-800 ms) parietal negativity that is larger for images that need to be rotated compared to ones that do not. As this negativity varied with the kind of test view, namely unusual versus canonical, it was associated with

mental rotation. Still, results from other studies are inconsistent with the idea of mental rotation. Gauthier et al. [Gauthier, 02a] studied fMRI activity during mental rotation and viewpoint-dependent recognition and found different neural substrates associated with viewpoint-dependent object recognition (ventral areas) compared to those ones related to mental rotation (dorsal areas). They conclude, "...that viewpoint dependent object recognition should not be seen as being mediated by mental rotation." ([Gauthier, 02a] p. 169). Arguments against mental rotation as a strategy to cope with changes in viewpoint has also come from primate studies, where separation in the cell response to different viewing circumstances occurred after response onset and amplified over time: "If cell responses would reflect mental rotation, then one would predict a systematic change in latency of response onset with change in view ...." ([Perrett, 98] 1998, p. 140).

1.3.2.2.2 Linear combination of views (Ullman & Basri, 1991)

This approach is based on the idea that the variability in a set of views of a single object is still influenced by regularities that can be perceived on the pictorial level. The views comprising the representation of an object are not only a connection of independent two-dimensional views, beyond that they are used in the recognition process in a collective manner. The theory of linear combination of views was proposed by Ullman & Basri [Ullman, 91] and postulates object representation by the linear combination of two-dimensional views. Coordinates (x, y) of three different views are supposed to be correspondent and constitute a set of view. A new image is presentable as a vector linear combined by the coordinates of the views within the set. The proposition assumes orthographic position and, critical for the range of rotation used in this study, a reliable discrimination by combination is expected with up to 60° rotation. Thus, an effect in reaction times is predicted because of the time consuming process of linear combination, that should not affect error rates because the stored descriptions of an object are transformed to an optimal configuration compared to the input. To represent an object from a wider range a number of different models will be required. Poor performance is expected on views that belong to an orthogonal space [Ullman, 98], as used in this thesis (frontal to profile and v.v.). The authors refer to computational studies [Ullman, 98] and psycho-physiological results which illustrates a persistent decrease in performance after pose change, even when the object is familiar to the observer.

1.3.2.2.3 View interpolation (Bülthoff & Edelman, 1992)

The view interpolation approach was introduced by Poggio and Edelman [Poggio, 90] and Bülthoff and Edelman [Bülthoff, 92]. The authors developed a scheme that is based on the theory of approximation of multivariate functions and that learns from a small set of views a function matching any viewpoint of an object or a face to a standard view. Thus, after encoding at least two views of an object, it will be recognized from any view. A view is represented as a 2N-vector x_1y_1, x_2y_2 ... x_Ny_N, representing the coordinates of feature points of the image. Mapping of familiar and unfamiliar views proceeds by interpolation of two-dimensional views: "...under a variety of conditions it appears that the visual system represents and recognizes objects through simple, but perfect, two-dimensional view approximation that does not involve three-dimensional object models or explicit and precise compensation for viewpoint variability." ([Bülthoff, 92] pp. 63). Interpolation is a two-stage process. First, intermediate responses are formed by a set of receptive fields reflecting prototypical stored or trained views. A Gaussian-shaped basis function is placed at each of these views. In a second stage unfamiliar views are approximated by a characteristic weighted sum of the Gaussians over the range of possible views. Thus, the object is recognized or rejected as being familiar. The authors assume the visibility of all features given at least by two images. In a sense, the application of the view interpolation method can be considered as a generalization of the linear combination of views as proposed by Ullman and Basri [Ullman, 91]. The view interpolation approach predicts increasing reaction times and error rates with increasing changes in viewpoint if the interpolation involves an incremental process, as for instance a spread of activation in a distributed implementation. Furthermore a lower error rate for familiar than novel test views depending on the distance from the novel view to the nearest familiar stored view is predicted ([Bülthoff, 95] p. 251). This was shown by the findings of Bülthoff and Edelman (1992) and Edelman and Bülthoff [Bülthoff, 92]. Their experiments consisted of a training phase and a test phase of amoeba-like and tube-like objects. In the training phase objects had been shown as a motion sequence of two-dimensional views. In the test phase the subjects were presented with single static views of either the target or a distracter. Bülthoff and Edelman [Bülthoff, 92] defined a viewing sphere of intra, extra and ortho conditions defining different training and testing views. The imaginary viewing sphere is centred about the target. Target test views were situated within the range of two training views (0°-

75°) in the inter condition or beyond (75°-360°) in the extra condition. In the ortho-condition the target was rotated orthogonally away from the training view. The results turned out to be similar faces [Wallraven, 02]. Error rates had been found to be highest in the ortho-condition, intermediate in the extra condition and lowest in the inter condition. Recognition performance was poor for radically unfamiliar views (60° view change from the familiar view). But even when the training and the test view had been learned, error rates increased with distance of more than 20° from training to test view, which supports the interpolation hypothesis and the storage of single two-dimensional images. Edelman and Bülthoff [Bülthoff, 92] explored the canonical view phenomenon and the role of depth cues (e.g. shading, lighting, texture properties) in recognition. The authors report instable canonical view effects the more an object was studied from different views. Thus the possibility of a conjunction of canonical views and mental rotations could be ruled out. For faces the canonical view effect by means of a ¾-view advantage turned out to be instable as well e.g. [Liu, 02a]. For canonical views in the sense of ¾-views have shown a performance peak in the opposite ¾ view only [Hill, 97], which supports the assumption of virtual views [Poggio, 92] caused by the symmetry of a face. The symmetry argument gave Poggio and Vetter [Poggio, 92] reason to introduce the idea of the transformation of non-accidental or canonical views into virtual views. Provided that an object is roughly bilateral symmetric and the trained view reveals symmetry (as in the case of canonical views) a symmetric virtual view from the only known view might be generated. In that sense learning of only one view of a face might be sufficient for recognition. Adding cues to depth to the target caused lower error rates and reaction times in recognition, which offers insights into the nature of stored representations that support object recognition. Edelman and Bülthoff ([Edelman, 92] p. 2399) conclude that representations may also consist of depth information encoded as a 2 ½ sketch according to Marr [Marr, 82], since depth cues facilitate recognition in a viewpoint-sensitive way. In reference to Bruce and Young [Bruce, 86c], depth cues and viewer-centred descriptions as a result of structural encoding, enter the face recognition units and are stored within them. Neuro-physiological support for representations in terms of discrete views was provided by the analyses of the formation of viewer-centred neurons in monkeys trained to recognize objects [Logothetis, 94] or faces [Hasselmo, 89b] [Perrett, 85] [Perrett, 90] across changes in viewpoint. In summary, the MVPT model which does not postulate mental rotation can account for

differences in reaction times as well as error rates in dependence of changes in viewpoint but does not account for recognition performance over large changes in viewpoint.

1.3.3 Theories that rely on two-dimensional representations of images and features

1.3.3.1 Featural and configural information in face recognition

Face recognition requires the processing of holistic surface-based information [Biederman, 98] [Farah, 95b] that integrates featural and configural (for spatial relations among features) information involving the whole image [Collishaw, 00] [Schwaninger, 02] [Leder, 01]. This is based on approaches that assume the combination of configural and featural aspects of a face and their contribution to recognition over changes in viewpoint as already postulated by Bruce and Young [Bruce, 86c]. O'Toole et al. [O'Toole, 94] [O'Toole, 98] looked in detail at the response pattern for different faces over changing viewpoints and came to the conclusion that there are two separate components that contribute to the recognition performance at different viewpoints. One correlates with the performance between frontal and ¾-views and another one between ¾- and profile views. O'Toole et al. [O'Toole, 98] tested a computational model that incorporated a viewpoint alignment operation and a recognition-by-interpolation operation. The facial information that underlies the alignment process might capture global distinctive aspects in one component (frontal to ¾) and more locally distinctive features in the other one (¾ to frontal). This supports the assumption that different rotations in depth produce different structural codes stored in memory.
Likewise, Collishaw and Hole [Collishaw, 00] and Schwaninger et al. [Schwaninger, 02] suggest face recognition as a process of both, local parts (features) and their spatial relationship (configural information). A computational implementation was provided by Schwaninger, Wallraven and Bülthoff [Schwaninger, 04]. The authors reduced either featural or configural information selectively by blurring or scrambling procedures. It was found that previously learned faces could still be recognized when scrambled into constituent parts. Then the blur level that made the scrambled parts unrecognizable was applied to whole faces. These configural versions of previously learned faces had been recognized reliably as well. This was found for familiar as well as unfamiliar faces. Consequentially an integrative model of face recognition is proposed. It is assumed that both, local feature-based and spatial relations are extracted from the facial image in order to activate featural and configural representations within the ventral stream, by means of

the face selective areas in the temporal cortex [Haxby, 00] [Gobbini, 07]. Featural and configural representations are thought to converge to a single face identification unit [Schwaninger, 02]. This assumption resembles the FRUs as proposed by Bruce & Young [Bruce, 86c] containing both two-dimensional image shots that reveal the configuration of facial parts as well as separate feature based information characterizing mouth, nose and eyes.

Neuro-physiological evidence supports feature-based as well as configural based processing assumptions. In primate studies Perrett et al. [Perrett, 82] found that faces are represented in the inferior temporal cortex of the macaque by a combination of cells, some that respond only to the whole face and some that respond to single features being independent of the presence of critical features for maximal activation (see [Rolls, 00] for a review). The same was found for complex objects as well [Tsunoda, 01]. Only few studies in primates report results being compatible with a primary holistic processing e.g. [Wachsmuth, 94].

1.3.3.2 Dual-strategy approach (Valentin, Abdi, Edelman, Posamentier, 2001)

In contrast to the assumption that multiple (or at least two) views are essential to recognize a face from an unfamiliar point of view, there are repeated empirical results demonstrating human performance - with respect to accuracy - being above chance level across large pose changes of 90° even when only one view had been learned before e.g. [Hill, 97] [O'Toole, 94] [Troje, 96] [Valentin, 01]. These results make the assumption of facial representations based solely on two-dimensional images less probable, because with viewpoint changes of this magnitude parts of a face will not be visible anymore, making an interpolation process impossible. A theory that incorporates view-independent descriptions of parts and view-dependent representations of images might be the most compatible model for object and face recognition on the subordinate level [Tarr, 98a].

Valentin and colleagues [Valentin, 97] [Valentin, 99] [Valentin, 01] investigated the information transfer from a single view to a new view of a face across large viewpoint changes and the effect of distinctive marks on the surface of frontal or profile faces within human and computationally simulated studies. Based on this Valentin and colleagues introduced their dual-strategy model for recognition of faces across view angles [Valentin, 97] [Valentin, 99]. Valentin et al. [Valentin, 97] concluded the existence of two distinctive recognition strategies used in dependency of the magnitude of view change. For large

rotations from the frontal view (40 - 90°) the dual-strategy hypothesis states that subjects base their decision on local information rather than configural information or spatial interrelationship of facial features respectively. When a small amount, or no, rotation is applied between learning and the test, subjects rely primarily on general configural information. Local information and configural information are thought to be two-dimensional presentations in memory. Testing the recognition performance for familiar and unfamiliar faces from frontal to ¾-view, from profile to ¾-view, from frontal to profile view and v.v., the authors found that orientation changes of faces between learning and test from frontal to ¾-view affected the recognition of unfamiliar faces, but not the recognition of familiar faces. When view change exceeded 30° recognition performance dropped dramatically for familiar as well as unfamiliar faces. When testing the effect of distinctive marks on the recognition of unfamiliar faces across view-angles, Valentin et al. [Valentin, 99] found that the effect of those marks was dependent on the view that had been presented during learning. The effect of a mark was highly significant when a full-face was learned, but not significant at all when a profile face was learned. Adding a distinctive mark on a face improved significantly the proportion of correct responses over large viewpoint changes (90°) but not in the conditions without view changes. The authors assume a shift in attention from texture, as captured from frontal images to shape encoding as captured from profile faces.

Valentin et al. [Valentin, 01] tested the information transfer from a single view to 0, 10, 20, 30, 40, 50, 60 and 90° between learning and test. Performance accuracy decreased as an inverse function of the rotation angle. A trend analysis revealed that 30% of the variance in accuracy performance could be explained by a non-monotonic linear relationship between angle of rotation and recognition performance. It was found that the ability of humans to recognize a face previously seen from a single viewpoint is nearly stable up to 30°, and deteriorates when the view is changed by more than 30°. Continuative tests have shown that the rotation conditions fall into two groups: 0 to 30° and 40 to 90°. Within the groups themselves variations turned out to be not significant. The authors conclude first, the non-monotonic shape of the relation between accuracy and rotation angle contradicts the mental rotation theory. In terms of mental rotation a monotonic function is predicted, characterizing the relationship between reaction time and performance. Secondly, different transfer strategies might be used as already suggested by the previously discussed studies.

Up to 30° of rotation the similarity between learned image and test image enables "transfer by configuration". Above 40° observers seem to transfer facial information that is invariant to depth rotation that allows recognition performance above chance level as localized information. Valentin et al. [Valentin, 01] named this strategy "transfer by peculiarity" by means of features extracted from a single view.
Support for this idea has been provided by Hasselmo et al. [Hasselmo, 89b] and Perrett et al. e.g. [Perrett, 85] who found neurons in the STS of primates that respond selectively to different gaze directions and different angles of profile. Many of these cells responded only to a particular orientation of a face or a direction of gaze, as either were full face, profile, back of the head, head up and head down. But a minority of cells was found to be insensitive to viewpoint changes. Results from PET and fMRI studies in humans support the idea of face recognition over changes in viewpoint as a process which allows for a transfer of invariant as well as view dependent aspects of a face. Some results suggest recognition across changes in viewpoint might be based on different neural subsystems. As outlined in 1.2.2.2 Rossion et al. [Rossion, 00a] found part-based recognition predominantly in the left fusiform gyrus compared to whole-face processing, found to be more pronounced in the right. Vuilleumier, Henson, Driver & Dolan [Vuilleumier, 02] found that particularly the activity in the right fusiform cortex changed in relation to changes in viewpoint of an object whereas activity in left fusiform areas was independent of viewpoint. Other fMRI studies of the FFA have utilized a finer grained analysis to investigate the representation of invariant aspects of a face [Eger, 04] [Eger, 05]. Eger et al. [Eger, 04] replicate former findings and point to a role of the medial fusiform face area in discriminating individual faces at a level of representations that is invariant to changes as spatial scale. The same invariance could not be detected in posterior occipital face-responsive regions. Eger et al. [Eger, 05] found view image-independent priming effects in the left anterior fusiform region for famous faces and Pourtois et al. [Pourtois, 05] found view-independent priming effects in the left temporal region. This supports the theory that a specific subsystem operates more effectively in the right hemisphere and stores objects viewpoint-dependently, while an abstract subsystem operates more effectively in the left hemisphere that stores objects in a view-independent way [Burgund, 00] [Pourtois, 05]. To summarize, the dual-transfer hypothesis provides an account of face recognition and generalization over large changes in viewpoint even after having seen just a single facial

image. Although, assumptions about the integration of configural and featural information are not made, it does offer some similarities to Bruce and Young [Bruce, 86c] who suggest that FRUs contain an interlinked set of structural codes for distinct head angles including codes reflecting the global configuration an others that represent particular features becoming active when a face is shown from any point of view ([Bruce, 86c] see 1.2.1.1).

1.3.4 Summary and Conclusion

Theories about the representation of objects and faces can be classified with reference to their assumptions about dimensionality (three- or two-dimensional), and the nature of the information that face recognition is based on, i.e. part- or feature-based, image- or configuration-based. One group of theories assumes that three-dimensional, object-centred representations based on either parts [Biederman, 87] or images [Moses, 96] [Ullman, 89]. Accordingly, objects can be recognized in a viewpoint-invariant manner. Still, Biederman [Biederman, 87] and Ullman [Ullman, 89] predicted viewpoint-invariance, by means of the absence of any effect caused by view change, only for objects on a basic-level and over limited range of view changes. That makes those theories inappropriate candidates to account for face recognition within a rather homogenous stimulus class over a wide range of viewpoint changes. Still, based on empirical results demonstrating viewpoint-independence in face recognition with respect to accuracy and to changes in head orientation from a frontal to a ¾-view and vice versa [Bruce, 82] [Davies, 78] [Patterson, 77] [Roberts, 89] and over extreme view changes exceeding ¾, the idea of extraction of components or features that are stable across view changes is plausible for the recognition of faces as well. Another class of theories postulates two-dimensional image-based representations, for which face recognition on a subordinate level is always viewpoint-dependent [Bülthoff, 92] [Ullman, 91] [Wiskott, 96]. There is a large body of empirical results showing performance effects while view was changed from the first to the second encounter of even highly familiar faces [Jemel, 03a] [Schweinberger, 02b] [Troje, 99], newly learned [Troje, 96] and unfamiliar faces [Bruce, 87b] [Bruyer, 89] [Hill, 97] [Krouse, 81] [Liu, 02a] [Wallis, 01]. Multiple views might be pooled into a single viewpoint-independent representation when faces are highly familiar to the observer caused by many different views that have been encountered before e.g. [Bülthoff, 95] [Schyns, 93]. The primary limitation of image-based representations is that experience with multiple views (at least two) of a face is essential to provide face recognition from an

unfamiliar viewpoint. Under extreme view changes recognition performance above chance level is not predicted. This is due to the fact that substantial portions of the stored image will not be visible when the viewpoint changes from, e.g., frontal to profile view, making an interpolation process impossible. This is contradicted by empirical results revealing that the encounter of a single view of a face is enough to produce reliable generalization performance as well. Human performance even across large pose changes of 90° is not perfect but still above chance level e.g. [Hill, 97] [O'Toole, 94] [Troje, 96] [Valentin, 97] [Valentin, 99] [Valentin, 01] thus making the assumption of facial representations based solely on two-dimensional images less probable. Therefore, it has been suggested that a model that accounts for face and object recognition on a subordinate level should incorporate aspects of both classes of theories [Tarr, 98a]. O'Toole et al. [O'Toole, 98] and Valentin et al. [Valentin, 97] [Valentin, 99] [Valentin, 01] argue that there are at least two separable components that contribute to recognition performance at different viewpoints. Following the dual-strategy approach introduced by Valentin and colleagues [Valentin, 01], face recognition relies on a combination of configuration-based and feature-based representations that make the recognition of even unfamiliar faces over extreme changes of viewpoint possible. Accordingly, features that distinguish a face from all other faces and being accessible from different viewpoints are extracted from the learning view. Wallraven et al. [Wallraven, 02] and Schwaninger et al [Schwaninger, 02] assumed that configural and featural information converge into one single face identification unit resembling the notion of FRUs by Bruce and Young [Bruce, 86c]. Viewpoint-independence might be achieved, based on two-dimensional representations of images (configuration) and features. Strong evidence for face recognition as being dependent upon viewpoint and being invariant for some aspects of a face have came from primate studies e.g. Perrett et al. [Perrett, 85] [Perrett, 98] and fMRI studies with humans [Eger, 05] [Pourtois, 05]. In *Table 1* the experiments are listed that investigated the effects of pose change from a learning to a test view, using familiar (newly learned and famous) and unfamiliar faces. Within empirical studies effects of pose change are reflected by the differences in the performance or neural response between the view-same and view-different conditions. Still, there is a large body of computational experiments in face recognition that focused on view dependency, the main aim here is to give an overview of human performance and neuro-physiological data resulting from recognition across viewpoint change experiments.

A comparative inspection of the studies listed in *Table 1* reveals that the effects of viewpoint on recognition performance and psycho-physiological data are unlikely to be absolute, i.e. to support clearly one of the outlined theories, as they depend on expertise (famous, familiar, newly learned, unfamiliar), facial information that is received during expertise (number of learned views), the task (matching to sample or familiarity decision), the angle of view change and the stimulus material itself with respect to external features. Roberts and Bruce [Roberts, 89], Schweinberger et al. [Schweinberger, 02b] and in the more recent fMRI studies e.g. [Eger, 05] compared the impact of image change on famous faces and unfamiliar faces. However, for famous faces many different views have already been stored in the memory, and whilst retrieval of any of their views provides recognition of that face it does not provide insight into the nature of underlying representations. The ability of the human visual system to generalize recognition from familiar to unfamiliar views gives a better insight into the nature of the underlying representations e.g. [Valentin, 97] [Valentin, 99] [Valentin, 01]. Most of the experiments used a matching to sample paradigm e.g. [O'Toole, 98] [Valentin, 97] [Valentin, 99] [Valentin, 01] [Wallraven, 02], only Schweinberger et al. [Schweinberger, 02b], Troje and Kersten [Troje, 99] or Roberts and Bruce [Roberts, 89] used a task that actually requires face identification. The question also arises of whether recognition accuracy when the view change exceeded 45° was a result of episodic memory where context facilitates recognition [Moses, 96] [O'Toole, 98] [Valentin, 97] [Valentin, 99] [Valentin, 01]. Concerning the studies by Valentin and colleagues [Valentin, 97] [Valentin, 99] [Valentin, 01] or Moses et al. [Moses, 96] external features like hairstyle might have additionally facilitated the recognition across large view changes. As the analyses of facial representations that are used to identify a face concerns the internal rather than external more changeable features of a face [Bonner, 03a] [Bruce, 86c] [Ellis, 79] [Young, 85b]. Following that the removal of features like hairstyle as done by Bülthoff and colleagues e.g. [Troje, 96] [Schyns, 93] [O'Toole, 98] focused recognition upon the internal aspects of a face.

Table 1: *Empirical findings and contributions to theories about facial representations*

AUTHOR	STIMULI, PARADIGM TASK	VIEW CHANGE	RESULTS
Viewpoint- invariance (reaction time / accuracy)			
Patterson & Baddeley (1977)	- Newly learned faces - Study – test (immediately)- Task: matching to sample	Frontal to ¾ and vise versa	- no effect on accuracy
Davies et al. (1978)	- Unfamiliar faces - Study – test (immediately)- Task: matching to sample	Frontal to ¾ and v.v.	- no effect on accuracy
Bruce (1982)	- Unfamiliar / familiar faces – Study – test (immediately)- Task: matching to sample	Frontal to ¾ and v.v.	- Decrease in accuracy for unfamiliar faces only - Increased reaction times for unfamiliar and familiar faces
Moses, et al.(1996)	- Unfamiliar upright and invrted; learned faces from a single viewpoint - Study – test (immediately) – Task: matching to sample	-34°, -17°, 0, 34°, 17° (largest view change between study and test: 51°)	- no effect on accuracy for upright faces- Inverted faces: performance decreased with view change: three-dimensional representation for upright faces
Roberts & Bruce (1989)	- Unfamiliar / familiar - Prime-target /intermediate face – Task: familiarity decision	Frontal to ¾ and v.v.	- Increase in reaction time for unfamiliar faces only
Viewpoint-dependence (reaction time / accuracy)			
Krouse (1981)	- Unfamiliar - Study – test (Immediately and 2-3 days delayed) – Task: matching to sample	Frontal to ¾ and v.v.	- Decrease in accuracy; lower accuracy in the delay condition - ¾-view advantage in the study view

Bruyer & Galvez (1989)	- Unfamiliar and familiar - Study-test (immediately)- Task: matching to sample	Frontal to ¾ view and v.v.	- Unfamiliar faces: ¾ view advantage in the recognition task irrespective of study view
Bruce et al. (1987)	- Unfamiliar and familiar - Study-test (immediately) – Task: matching to sample	Frontal to ¾ and profile; ¾- to profile view and v.v.	- Increase in reaction time depending on view change - unfamiliar faces: ¾ study-view advantage
Kalocsai et al. (1994)	- Unfamiliar faces *(External features removed)* - Study –test (immediately) – Task: matching to sample	From left 20° to right 40°	- Increase in reaction time and decrease of accuracy depending view change relative to study - linked to the fiducial point model (Wiscott et al. 1996)
Results compatible with the multiple view plus transformation theory (Tarr & Pinker, 1989)			
Schyns & Bülthoff (1993)	- Unfamiliar, newly learned; *(External features removed)* - Study –test (immediately) - Task: matching to sample	Faces learned from: *Exp. 1*: left 36, 18, 0, right 18 and 36° *Exp. 2*: left 36, 18, 0, right 18 or 36°	*Exp. 1*: no effect on accuracy, when all views are learned; no ¾ study view advantage *Exp. 2*: ¾ study view advantage - Integration of different views into a single representation
Troje & Bülthoff (1996)	Unfamiliar, newly learned *(External features removed)* - Study –test (immediately) - Task: matching to sample + Intermediate mask	Study and test: 0°, 22.5°, 45°, 67.5°, 90° largest change 90° and 180° contra lateral	- Decrease in accuracy dependent on view change and ¾ study view advantage - contra lateral view advantage supports the virtual view hypotheses (Poggio et al., 1992)
Hill et al. (1997)	- Unfamiliar; *(External features removed)* - Study –test (immediately)- Task: matching to sample	left 90°, left 45°, 0°, right 45°, right 90° Faces learned from one or five views	- Decrease in accuracy, increase of reaction time dependent on view change; no ¾ study view advantage - Symmetry effect for ¾ view
Troje & Kersten (1999)	- Familiar and highly familiar (observers own face) - Naming task	Either 0° or 90°; no pose change	- View dependency even in highly familiar faces - Profile view of one's own face treated like an unfamiliar face

Wallis & Bülthoff (2001)	- Unfamiliar *(External features removed)* - Study –test (immediately) – Task: matching to sample	Changed identity of faces while rotating from 90° left to 90° right	- Spatiotemporal sequences led to association of image views, images treated as if they were from the same person: support for MVPT theory
Liu & Chaudhuri (2002)	- Unfamiliar; newly learned *(External features removed)* - Study –test (immediately) – Task: matching to sample + Intermediate distracter faces	Faces learned from frontal, ¾, profile view Two levels of training (one or two sessions)	- Accuracy and reaction time affected by the level of training; no ¾ view advantage - no learning view effect
Results compatible with the dual strategy approach (Valentin et al. 2001)			
O'Toole et al. (1998)	- Unfamiliar; newly learned (External features removed) - Study –test (immediately) – Task: matching to sample	Pose changes 0°, 45°, 90°, no contra-lateral views Faces learned from 0°, 45°, 90°	- Decrease of accuracy dependent on view change: two separable components that contribute to the recognition performance across view change - one componant that correlates with performance from 0 to 45°one from 45° to 90° as associated with configural and local distinctive features
Valentin et al. (1997)	- Unfamiliar; newly learned- Study –test (immediately)- Task: matching to sample	Study and test views: 0°, 45°, 90°; Largest view change 90°	- View changes between 0°-45°: no accuracy effect; 45°-90° strong decrease of accuracy; - Highest accuracy for ¾ view even when it was not learned
Valentin et al. (1999)	- Unfamiliar faces with and without distinctive marks - Study – test (immediately) – Task: matching to sample	Study and test views (0° and 90°) view change frontal to profile and v.v.	- Effect of distinctive marks for frontal study view in the 90° view change condition only - different types of information are used depending on the learning view

Valentin et al. (2001)	- Unfamiliar; newly learned - Study –test (immediately) - Task: matching to sample	Study and test views: 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°; largest view change 90°	- non-monotonic linear increase of reaction time and decrease in accuracy dependent on view change: different transfer strategies (0°-30° transfer by configuration 30° - 90° transfer by peculiarity, i.e. features)
Wallraven et al. (2002)	Unfamiliar; newly learned (External features removed) - Study –test (immediately) - Task: matching to sample	Study: 0° / 60° Test: "inter" = within learned views; "extra" = beyond learned views; view changes in 15° steps	- Decrease in accuracy dependent on view change - Recognition accuracy better in the "inter"–condition than in the "extra" condition: Facial representations consist of viewpoint-dependent featural (part-based) and configural information
Viewpoint-dependence and viewpoint-invariance in neurophysiological data EKPs / fMRI-Results			
Jemel et al. (2003)	- Famous and unfamiliar - Repetition priming (continuous performance) + InterveningObjects) - Task: Living or non-living decision	same or different image presented as a prime	- only repetition of the same picture caused a ERE from 350 ms
Schwein-berger et al.(2002b)	- Famous and unfamiliar - Repetition priming / immediately - Task: Familiarity decision	Same or different image presented as a prime	- Reaction time, accuracy and repetition effects (ERE) reduced when image was changed from prime to target: support for multiple view theory
Eger et al. (2005)	- Famous and unfamiliar - Repetition priming (continuous performance intermediate stimuli) - Task: gender decision	Same or different image presented as a prime	- for famous faces only: generalization of repetition effects in left anterior fusiform cortex: multiple views might be integrated to a single view independent representation

Pourtois et al.(2005)	- Famous and unfamiliar - Long-term repetition priming (Inter-Stimulus-Intervall = 4800 ms) - Task : gender decision	Frontal to ¾ view and v.v.	- Bilateral fusiform areas showed generalization from ¾ to frontal view only - left middle temporal and inferior frontal cortex: repetition effects across all types of view changes - View invariant regions in the fusiform cortex; only view sensitive information is represented bilaterally
Viewpoint-dependence and invariance found single cell recording studies with non-human primates			
Perrett et al. (1985)	- Faces and other stimuli continuously presented - visual discrimination task	Stepwise rotation of the heads from 0°, 45°, 90° to 180°	- Cell populations in the STS: 2/3 of the face selective cells orientation sensitive; (to frontal, 45° or 90° views): delay in activation; 1/3 of the face selective cells insensitive to viewpoint: similar response latencies - View insensitive cells: respond to a feature common to all views
Hasselmo et al. (1989)	- Primates watched head movements performed by the experimenter	Rotating heads from the front view to 90°	- STS: view specific and view-point-independent represen-tations are built in the inferior temporal visual cortex
Perrett et al. (1991)	- real threedimensional heads (experimenters) and 2D images presented - Task: visual discrimination task	Presentations from 0°, 45°, 90° and back of the head of the head	- Majority of cells in the STS are viewer-centred and exhibit tuning to one view, with more of the cells being tuned to frontal, ¾ or profile view and a minority of cells (25%) are face-centred (object-centred)

To conclude, a study that seeks to analyse facial representations with respect to their content and dimension has to include a task that requires identification of a face using stimuli that focuses the internal aspects of a face, a comparison of face recognition that relies upon configuration, i.e. no view change or view change below 30°, with face recognition that relies on features, i.e view changes that exceed 40° and faces being, in

both cases, familiar with respect to a single point of view. The impact of learning view towards recognition performance has to be analyzed. Clearly, recognition across view change that is still above chance, would contradict theories that rely exclusively on the storage of multiple views e.g. [Bülthoff, 92]. Besides performance data (reaction times and percentage of errors) ERPs that are specifically associated with the activation of facial representations on a pre-semantic level (ERE) would also provide information revealing underlying neuronal sources that are associated with the activation of facial representations [Schweinberger, 02b]. Concurrent sources would suggest the integration of images by means of configuration and extracted features into a single representation, as predicted by multiple view theories e.g. [Schyns, 93], by theories that assume the storage of both configuration (images) and features e.g. [Schwaninger, 02] and by Bruce and Young [Bruce, 86c] with reference to the FRUs.

1.4 Methodological background

This thesis seeks to answer two questions: Firstly, does the ERE as an electrophysiological correlate indicate the activation of stored representations of faces on a pre-semantic level of face recognition? Secondly, how sensitive are facial representations and the ERE respectively, concerning changes in viewpoint from the first to the second encounter? In order to answer these questions the ERE must be validated as being representative for facial representations in memory. Thus preliminary to the study concerning the view-point dependency facial representations, a repetition priming paradigm with backward masking was tested to identify and separate perceptual- and representation-based processes when a face is recognized. Subjects were required to perform a familiarity decision task or a semantic decision task. Why this paradigm was chosen as well as difficulties in interpreting these priming results will be outlined and discussed in the following subsections.

1.4.1 Priming

In 1.2.1.2.1 repetition and semantic priming is considered in the light of the IAC model by Burton et al. [Burton, 90]. The following describes in particular repetition priming as it reflects implicit or non-declarative memory (for reviews, see [Gabrieli, 98] [Richardson-Klavehn, 88] [Squire, 00]. The prototypical priming experiment consists of two stages that form the study-test-paradigm. In the first stage the participant is presented with a target-stimulus. In the second test stage, which follows the study stage within an interval of

milliseconds to one month, the participant is presented with the target again and asked to recognize it within a direct, e.g. matching to sample, or indirect memory test, e. g. semantic decision task about nationality. When the stimulus (a face) had been encountered recently, as in the study-test-paradigm just described, an improved ability to identify that stimulus (same face) occurs. The first encounter leads to the activation of visual and/or cognitive representations of that stimulus that leads to a subsequent increase of accessibility and makes it more likely to be used. Thus, priming is manifested behaviorally in shorter reaction times to the second presentation of the stimuli and to less error prone responses and can be visualized as differences in ERPs to the second encounter. A priming effect is reflected by the difference between a primed target and an unprimed target (stimuli that are presented for the first time) and is regarded as a correlate of memory. Direct or explicit tasks, e.g. matching to sample tasks, require primarily intentional retrieval (episodic memory) and indirect or implicit tasks evoke mainly unintended, automatic retrieval (implicit memory), e.g. the repetition of non-targets [Boehm, 05]. Priming effects develop quickly, can be very long lasting and can occur even in the absence of remembering the recent encounter [Roediger, 90].[5]

The repetition priming effect is linked to changes in neural response in two different ways. On the one hand it is suggested that repeated experience with novel stimuli causes a sharpening process of the stimulus representation in the cortex. Thus, only the critical features needed to identify the stimulus are represented in the cortex. On the other hand neurons show a decreased response. These neurons might have dropped out of the responsive pool because they encode less stimulus specific features. In relation to that, a consistent finding, especially for perceptual and repetition priming respectively, is the relative reduction of the neural response to repeated compared to visual stimuli initially presented. This was found especially in neurons of the inferior temporal cortex in monkeys, a phenomenon called “repetition suppression” e.g. [Baylis, 87] [Miller, 91a] [Desimone, 96]. The properties of repetition suppression match the behavioral

[5] Repetition of either the same or a similar stimulus that evokes inhibition rather than facilitation, often referred to as “negative priming” [Tipper, 85] is not of methodological concern in this thesis.

characteristics of perceptual priming: it is long lasting (occurs even if more than 150 items intervene), stimulus specific, shows graded response and is resistant to manipulations of particular stimulus attributes and awareness [Wiggs, 98]. Henson, Shallice and Dolan, [Henson, 00] specified the repetition suppression effect to the familiarity of faces and symbols. A right fusiform region responded attenuated to the repetition of familiar stimuli but showed enhanced response to the repetition of unfamiliar stimuli. Henson et al.[Henson, 00] revealed a repetition suppression effect for implicit tasks, but only for famous faces in the right lateral fusiform region and for both famous and unfamiliar faces in the left inferior occipital region. The "repetition enhancement"- effect for unfamiliar faces was attributed to gradual formation of new perceptual representations. Priming related increases in activation have occasionally been observed in single repetition experiments as well. Further research is needed to clarify how function changes as observed during early stages of item repetition. Such changes might reflect the transition of a brain pathway underlying task performance with novel items to a pathway driven by automatic response selection for items that had been repeated extensively [Schacter, 98].

1.4.1.1 Priming and memory systems

The core of this thesis is to investigate facial representations on a pre-semantic level using repetition priming. A familiarity decision task (Experiment I and III/recognition session 2) or a semantic decision task (Experiment II and III recognition session 1) is to be answered referring to a target that is repeated (primed) or not repeated (unprimed). The relation of prime and target is not mentioned by task instruction and the task does not require explicit comparison of prime and target (see Appendix F). In that sense, the tasks used in the experiments of the present thesis are rather implicit than explicit.
In contrast to explicit priming tasks implicit priming tasks do not require conscious recollection of any precious experiences or study phases. Implicit priming is a type of implicit or non-declarative memory [Schacter, 90]. Still, indirect priming has affinities to both procedural (implicit, non-declarative) and episodic and semantic memory (explicit, declarative). It resembles procedural memory in that it enhances perceptual skills. It resembles episodic and semantic memory in that it involves cognitive representations of the world ([Tulving, 90] 1990, p 301). Initial evidence for the dissociation of explicit (declarative) and implicit (non-declarative) memory came from patients with anterograde amnesia that show priming effects in a word-stem-completion-tasks comparable to healthy

subjects, while tests of explicit memories had been performed on a chance-level [Graf, 85] [Warrington, 74]. The idea is that the brain damage selectively affects the memory system for conscious recollection, but leaves the system responsible for other forms of retrieval intact e.g. [Squire, 87] [Squire, 93] [Squire, 00]. On the other hand Gabrieli, Fleischman, Keane, Reminger and Morrell [Gabrieli, 95] presented a patient who showed intact explicit and impaired implicit visual memory for words, corresponding to a lesion in the right occipital lobe. These findings support the view that at least perceptual priming depends on a brain system that is distinct from the system that supports explicit memory [Schacter, 98].

Tulving and Schacter [Tulving, 90] have proposed the existence of a perceptual representation system (PRS) that contains perceptual (abstracted physical), but not semantic codes of previously studied stimuli. The PRS consists of a number of subsystems, one of which is a structural description system that computes information about global form and structure of visual objects within units of memories. Moreover the PRS comprises perceptual memory processes that store information at less abstract levels of representation and provide input to the structural description system. Repetition priming of facial images is an expression of the perceptual representation system in general that operates on a pre-semantic level. With respect to the subsystems it can be attributed to either facilitation of perceptual processing or is mediated by abstract object representations that already exist in memory [Schacter, 94] [Magnussen, 00]. According to the PRS operating on a pre-semantic level supposed by Tulving and Schacter [Tulving, 90] and Hamann and Squire [Hamann, 97] concluded that because it can be produced in the absence of conscious remembering, priming appears to reflect neural changes within perceptual processing systems that occur before information reaches brain systems that transform visual perception into conscious visual memory. In connection to an implicit priming task, priming effects indicate mainly implicit processing demands. Further evidence supporting this view comes from repetition priming experiments with faces as discussed in the following chapter.

There are some issues to keep in mind while evaluating repetition priming effects. The phenomenon of dissociation between intended and automatic retrieval is also well known in prosopagnostic patients in terms of covert and overt recognition. Covert recognition of faces in Prosopagnosia means that patients cannot overtly recognize faces but manifest

recognition when tested in indirect ways [Farah, 93]. Thus, covert recognition in Prosopagnosia shows an unconscious access to face memory representations.
It is subject of some controversy as to whether covert recognition reflects the function of different memory processes that are mediated by different neural mechanisms or whether it is based on a disconnection of the face recognition system from processes that signal recognition to an awareness system [DeHaan, 99], or whether overt and covert recognition are mediated by the same functional systems [Burton, 91] [Farah, 93] [Schweinberger, 03]. This is critical for interpreting priming results in the sense of explicit and implicit memory. As said before, implicit priming studies assess the influence of information acquired during a study episode on subsequent performance with an implicit memory test. This test does not require conscious recollection of the study in terms of episodic memory. However, that a test does not require explicit remembering of a prior episode does not preclude the possibility that subjects will make use of explicit retrieval strategies on anatomically implicit test [Schacter, 90] [Jacoby, 91]. When stimuli are presented repeatedly processes explicit and implicit memory occur together [Boehm, 08].
Attempts have been made to disentangle the influence of different processes on performance measures. Jacoby [Jacoby, 91] proposes a two-factor theory of recognition memory even when the task is an indirect one. Accordingly, recognition memory always combines two factors, in which one factor relies on automatic processes and the other on intentional processes as a retrieval of memory of prior episodes, critically discussed by Curran and Hintzmann, [Curran, 95]. Schacter et al. [Schacter, 90] proposed a “retrieval intentionality criterion”. They argue that the same cues should be presented to subjects on implicit and explicit tests. Thus, implicit / explicit dissociations could be detected. This has led to studies that have investigated explictit-implicit memory dissociation using word stimuli [Badgaiyan, 97] [Paller, 98] [Hamann, 97] [Rugg, 98] and faces [Bentin, 88] [Henson, 02].
Bentin & Moskovitch [Bentin, 88] demonstrated task dependency of repetition priming for unfamiliar faces being reflected in performance data. Using an indirect priming task, no priming was observed when prime and target where separated by intervening items. In an explicit recognition task, priming was observed with as much as 15 intervening items. The study by Henson et al. [Henson, 02] investigated face repetition effects in implicit (familiarity judgment) and explicit (episodic recognition judgments) memory tests. For

both familiar and unfamiliar faces the "repetition suppression"– effect, as described above, was observed in the implicit task only, although with a different pattern for familiar to unfamiliar faces which supports the idea that implicit and explicit memory processes are mediated by different neural mechanisms.

Several ERP studies in face recognition provide evidence of implicit memory being different from explicit memory [Boehm, 05] [Joyce, 05] [Münte, 97] [Paller, 99] [Paller, 03a] [Trenner, 04]. Trenner et al. [Trenner, 04] compared the ERE and the LRE in direct and indirect tasks using identical trial presentations. Independent from the task these components reflect facilitation on different stages of face processing and will be introduced in detail in 1.4.2. Substantial task effects were demonstrated in ERP components from 250 ms after stimulus presentation onwards. The components differed in amplitude strength, meaning the amplitudes were larger in the direct task. Trenner et al. [Trenner, 04] concluded that the early and the late repetition effect are sensitive to task relevance and attention focus. Boehm et al. [Boehm, 05] found in a direct memory test an early frontal positivity and a late parietal positivity to repeated targets using a modified Sternberg-task. These effects resemble early and late repetition effects reported by Schweinberger et al. [Schweinberger, 95] and Pfütze et al. [Pfütze, 02] evoked using an implicit priming task but were sensitive to the level of processing during encoding. Hence, there is a degree of strategic, task-induced influences on each of these stages. None of these components of repetition effects reflect a purely automatic facilitation of processing or implicit memory alone.

Paller et al. [Paller, 99] and Paller et al. [Paller, 03a] produced perceptual priming in the absence of conscious memory by varying the study-conditions of two different sets of faces. The faces appeared again in an implicit or an explicit memory test. Neural correlates of priming as associated with implicit memory began from 270 ms after face onset, with frontal negativity showing for repeated rather than new faces. Remembered faces activated instead a different configuration of intracranial sources producing positive potentials 600-700ms which were correlated to the explicit memory task.

Beside ERP differences due to the repetition of familiar and unfamiliar faces the so-called old/new effect, as a greater positivity for old in contrast to new faces, was demonstrated in implicit and explicit memory tests [Rugg, 95] [Rugg, 00]. Two topographically distinct ERP correlates of recognition memory had been linked to familiarity and recollection as

distinct expressions of explicit memory to faces e.g. [Herzmann, 07] [Johansson, 04] and words e.g. [Wolk, 06]. The FN400 occurs as a mid-frontal effect from 300 to 500 ms and the Late Positive Complex (LPC) as a parietal effect around 400 to 800 ms (Curran, 2000; 2004). According to the remember/know paradigm by Tulving [Tulving, 85], "know" responses are given when subjects believed that items were studied but contextual information was not available to them. These responses are associated with the FN400. "Remembered" responses involve the retrieval of context information and are associated with the LPC e.g. [Wolk, 06] Still, the association of the FN400 with familiarity in the sense of pure explicit memory is controversial discussed e.g. [Paller, 07; Rugg, 07] [Rugg, 07]. Joyce and Kutas [Joyce, 05] compared the fronto-central positivity for "old" faces compared to "new" faces, i.e. the FN400 and LPC, with the ERE (N250r). The FN400 and the LPC varied with delay and the correctness of response. The ERE was detectable even for "old" but unrecognized faces. Following that, the ERE appeared to be independent of explicit memory processes reflecting implicit recognition.
Further research is needed to disentangle differences between explicit and implicit memory processes and thus, reliably to control their contributions to priming effects and different processing stages.

1.4.1.2 Repetition priming in face recognition

The following describes repetition priming in terms of the model by Bruce and Young [Bruce, 86c] and compiles results based mainly on performance data. Electrophysiological data is outlined in detail, when ERPs are described separately in 1.4.2.
Repetition priming is defined as a gain in item recognition after previous exposure. In repetition priming studies stimuli are either repeated or not repeated whilst participants usually have to perform a categorization task. Different study-test paradigms can be employed to investigate repetition-priming effects to facial stimuli. Therefore, faces can be presented within a prime-target-paradigm [Schweinberger, 95] or within a continuous-performance paradigm with intervening items [Pfütze, 02]. Here the latency between prime and target is relatively short. Furthermore faces can be learned within a study phase and recognized during a test phase among other new faces that follows the study face [Paller, 00] meaning that the SOA from prime to target is relatively long. Repetition priming has been used with regard to identification of a face, often connected to a familiarity decision task e.g. [Ellis, 96a] [Schweinberger, 95] Pfütze, 2002). Alternatively repetition priming

has been studied using a nationality decision task [Burton, 98], classifying familiar faces by occupation [Ellis, 90] [Young, 88] or naming tasks [Ellis, 96a]. There remains, however, are several restrictions and characteristics on the occurrence of repetition priming. This is important for the theoretical accounts of repetition priming effects and supports structural theories like the IAC – model by Burton et al. [Burton, 90] as introduced in 1.2.1.2 rather than theories that take episode-based memory into account [Jacoby, 91].

Ellis et al. [Ellis, 90] found that some decisions made about familiar faces benefit from repetition while others do not. The experiments by Ellis et al. [Ellis, 90] suggest that repetition priming of face stimuli is a consequence of changes within the system that responds to the familiarity of faces only. Thus, repetition priming affects the FRUs [Bruce, 86c] that contain stored descriptions of a familiar face. Within a first practice-phase of the experiment participants had to perform different task as classifying faces by occupation, by expression (smiling or unsmiling) or by gender. In the test phase the semantic decision task about occupation that requires identification of a face and hence the activation of the related FRU, yielded priming effects only. Expression or gender decision tasks did not evoke priming effects. (Still, Goshen-Gottstein and Ganel [Goshen-Gottstein, 00] found repetition priming with a gender decision task for edited, hair-removed, photos of unfamiliar and familiar faces suggesting that gender and familiarity decisions are mediated by a common route.) The nature of the initial response to a face was irrelevant to later manifestation of repetition priming when a familiarity decision was performed. If priming was caused by a visual analysis of the stimulus only and thus, depending on memory for previous processing episodes, priming must have been found irrespective of a familiarity, gender or expression decision task.

This is compatible with earlier experimental evidence that decisions about expression e.g. [Young, 86b] or gender [Bruce, 87a] derived from a face are not affected be familiarity of that face (see 1.2.1.1). Brunas, Young and Ellis [Brunas, 90], provide more evidence for automatic (implicit) rather than strategic aspects of processing. The authors demonstrated repetition priming of incomplete familiar faces. Participants had to perform familiarity decision tasks to faces of famous people primed by either previously presented internal features of the face, the external features of the face or the complete version of the face. All primed conditions revealed comparable priming effects. This demonstrates the

properties of the representations used in processing faces that contain global configuration as well as particular distinctive features [Bruce, 86c]. Brunas et al. [Brunas, 90] explain their results on the basis of parallel-distributed processing models (PDP) proposed by McClelland and Rumelhart [McClelland, 85]. In PDP models information processing takes place through the propagation of activation among simple neuron-like processing units rather than activation of information stored in logogens or recognition units. Patterns of activation are formed over the units through their excitatory and inhibitory interactions. The memory trace of an event is the increment to the strength of the interconnections of a specific pattern (for a review see [McClelland, 03]). Results by Brunas et al. [Brunas, 90] support the view that the property of pattern reinstatement on the basis of limited input data (as parts of faces) operates for pattern recognition in general, as well as, for faces in particular. Repetition priming resulting from a prior encounter with part of a face should be identical to the pattern that is activated when the whole face is initially seen, because the activation levels should be comparable in each case or when activation operates on an all or nothing basis.

More supporting evidence for the dissociation of repetition priming and episodic memory came from Bruce et al. [Bruce, 98]. The authors have shown that priming was independent from contextual changes in reference to the situation (laboratory or a different context), where the prime was seen (note that the delay between prime and target was 2-4 days). This contradicts the concept of an episodic influence on face priming.

Hay and Young [Hay, 82], Bruce and Valentine [Bruce, 85] and Bruce & Young [Bruce, 86c] assumed that representations used to determine the familiarity of a face are abstractive representations, being insensitive to changes in the surface form of familiar stimuli. Results by Bruce & Valentine [Bruce, 85] and Ellis, Young, Flude & Hay [Ellis, 87] suggest additional priming when a familiarity decision is required that traces back to the pictorial analysis of a given stimulus generated by activation of the viewer-centred descriptions. Ellis et al. [Ellis, 87] showed that repetition priming is sensitive to the degree of similarity between two different photographs when one is used as the prime stimulus and the other as test stimulus. This graded similarity effect was strongest when the study stimulus and the test stimulus were identical in pictorial aspects as well as in identity. Thus, repetition priming combines a perceptual-and a representation-based locus both causing improved identification. Adding support to the findings that repetition priming was demonstrated for

unfamiliar faces as well as for familliar [Bentin, 88] [Boehm, 06b] [Itier, 04a] [Schweinberger, 95]. It was, however, found to be significantly smaller as compared to familiar faces and this priming effect could only be found when the (unfamiliar) face is repeated contemporary to the initial encounter [Schweinberger, 95] [Schweinberger, 02a]. Thus, repetition priming of unfamiliar faces depends on the short-term activation of visual representations that may be of a structural or a pictorial type. Pictorial and structural information contribute to a perceptual-based part in repetition priming that in turn triggers the access to stored representations of familiar faces. Further evidence was found recently by Boehm et al. [Boehm, 06b] [Boehm, 06a] investigating the influence of face inversion in combination with intervening faces between the initial and second presentation on repetition priming of both familiar and unfamiliar faces. That is unfamiliar faces showed priming of perceptual locus (upright to upright priming) and no priming from the representation based locus (inverted to upright priming). Further evidence came from Goshen-Gottstein and Ganel [Goshen-Gottstein, 00] and ERP studies by e.g. Schweinberger et al. [Schweinberger, 95; Pfütze, 02] Pfütze et al. [Pfütze, 02]; Boehm et al., [Boehm, 06a]) that are outlined in 1.4.2.3.
In summary, repetition priming in connection to an implicit priming task causes a change in activation of facial representations rather than indicates episodic memory. It combines perceptual-based as well representation-based priming on a pre-semantic level.

1.4.1.3 Backward masking of face primes

Visual masking is a technique commonly used to disrupt the processing of a visual stimulus, which otherwise may continue to be processed after it has been terminated. Masking restricts the systems involved, in information processing, indirectly. For instance, Roberts & Bruce [Roberts, 89] have shown diminished priming effects in the masked condition relative to an unmasked condition. When unfamiliar and masked faces had been primed by a different view, priming was no longer seen [Roberts, 89]. As outlined in the foregoing chapter repetition priming combines perceptual-based (pictorial and structural) and representation- based contributions. Perceptual priming facilitates pictorial and structural analyses generated by activation of the view-centred descriptions and facilitates access to pre-existing representations of familiar faces. The aim of this thesis is to investigate the characteristics of representation based priming effects. By utilizing the terms of the Bruce & Young model [Bruce, 86c], conclusions about the architecture of the

stored structural representations, namely the FRUs, can be drawn. To impede perceptual–based priming effects and to extract representation-based priming, a backward masking paradigm was initially evaluated and later employed. The relationship between conscious and unconscious processing has been investigated when the masked stimulus is presented only very briefly e.g. [Marcel, 83] [Dehaene, 98]. Unconscious processing of facial expressions has been investigated by Esteves and Öhman [Esteves, 93] and Whalen et al. [Whalen, 98]. Masked priming paradigms are utilized to explore the early processes in face recognition concerning holistic and configural aspects [Williams, 04] or to investigate the processes involved in perception and memory within a direct-indirect task comparison [Martens, 06] [Trenner, 04]. Backward masking was employed in several face recognition studies seeking to investigate view changes, in order to avoid retinal after images [Troje, 96].

Masking refers to a class of phenomena where presentation of one stimulus (the mask) can impair performance on some task that requires judgment about another stimulus (the masked stimulus). Masking is a function of stimulus onset asynchrony (SOA) and inter-stimulus interval (ISI) and of the type of the mask type e.g. [Turvey, 73] [Moscovitch, 88]. Even when the masked stimulus is clearly visible (more than 200ms) and the subsequent mask stimulus is presented a hundred milliseconds after the masked stimulus is turned off, the observers' task remains exceedingly difficult. When the mask appears right after the stimulus that has to be masked (ISI = 0) and the SOA is very short (less than 200 ms) observers identify the masked stimulus at a random level only [Francis, 03]. There have been two theories of backward masking: interruption and integration [Francis, 03]. Interruption means that the mask stimulus interrupts the perceptual or cognitive processing of the masked stimulus. The time this process takes hinders the observers' performance directed to the masked stimulus. Integration refers to the combination of the mask and the masked stimulus to a single stimulus, which makes an observers decision about the target more difficult. A quantitative specification of underlying mechanisms was reported by Breitmeyer and Ganz [Breitmeyer, 76]. The authors developed the dual channel theory. It is based on the relation of transient and sustained visual channels to the magnocellular and parvocellular visual channel identified in animal neuro-psychology. Sustained channels are involved in relatively slow processing of object features, such as brightness, edges or figural details. Transient channels are involved in fast pattern

processing that signals the spatial location (motion) of a stimulus. In backward masking representations of the masked stimulus in the sustained pathway (slower) are inhibited by representations of the mask in the transient (fast) pathway (for a review, see [Breitmeyer, 00] [Ogmen, 03]). In cognitive sciences backward masking has been used to identify details of perceptual and cognitive processes. Accordingly Potter [Potter, 76] postulated that a mask following the offset of a picture could have a perceptual masking effect and / or a conceptual masking effect. A perceptual mask may be defined as one that inhibits the operation of the perceptual processes, whereas a conceptual mask inhibits conceptual processes. Loftus and Ginn [Loftus, 84] showed that perceptual and conceptual masking depends on the ISI and on mask type. Mask luminance affect perceptual masking and the amount of attention demanded by the mask (low attention = noise mask; high attention photograph similar to the target that changed from trial to trial) would affect conceptual masking. They report that only when the mask immediately follows the target (presented for 50 ms), is there a large effect of luminance but no effect of attention demand. When the mask is 300ms delayed, there was no effect of luminance but an effect of attention demand. This suggests that when the ISI = 0, that there is only perceptual masking, this is essential for the aim of this thesis to separate perceptual from representation based priming.

Costen, Shepherd, Ellis and Craw [Costen, 94] studied the amount of masking induced by different mask types. They compared the mask effect of facemasks, with the effect of well-known object masks, unstructured noise masks, jumbled facemasks and no mask using a backward masking paradigm. Subjects had to perform a naming and a recognition task. There was no ISI between the masked face and the mask. The SOA was variable with a feedback system in which SOA varied in order to ensure an accuracy of 50%. The display times of the mask were equal to the time the masked face was displayed. [Costen, 94] were able to demonstrate a masking effect only for face masks, but neither object masks nor noise masks yielded masking effects. Intermediate levels of masking were seen from face masks that had been inverted, jumbled or their inner features removed. (The jumbled mask type will be referred to as “scrambled” later on.) Similarity between a mask and a masked face did not interact with the mask effect. No interactions with the task were revealed. Costen at al. [Costen, 94] conclude that the masking seen between faces reflects the operation of a face-specific process. In terms of information-processing models of face

recognition the data suggest that masking occurs within the visual coding system after a face had been categorized as a face. Thus, masking was localized to the structural encoding level, namely FRU activation.
In summary, masking the prime face when the mask follows the prime immediately (ISI = 0) should diminish the perceptual part of these representations and the features of representation based contributions to priming of face recognition can be studied.

1.4.2 Electrophysiological correlates of face processing and repetition priming

Face processing has been intensively studied using other various approaches such as intracranial recordings e.g. [Allison, 99] PET and fMRI studies e.g. [Haxby, 00]; [Kanwisher, 97] or neuropsychological reports of prosopagnostics [Damasio, 82]. Of major relevance to the studies presented in this thesis are electrophysiological investigations, namely event-related potentials (ERPs) recorded from the surface of the scalp. PET, fMRI as well as ERPs suggest face-processing specificity and have complementary advantages. PET and fMRI are two techniques that may reveal task related increases in regional cerebral blood flow that indicate increases in neural activity. Thus, brain generators involved in e.g. face processing can be localized. But, because of the poor temporal resolution (a few seconds) the sequence of the activity of those generators is much more difficult to analyze [D'Esposito, 99]. ERPs provide answers to this time course question, because they measure changes in task-related neural activity within milliseconds. ERPs are voltage fluctuations that are time-locked to the occurrence of a stimulus, extracted from the electroencephalogram (EEG) by filtering and averaging [Picton, 00]. ERPs reflect the summed activity of neural populations by means of voltage differences along a time continuum that starts with the presentation of a stimulus. The individual neurons belonging to that population must be synchronously active and must have a certain geometrical configuration producing measurable fields at the scalp. Such “open fields” are characterized by parallel alignment of neurons. Scalp related ERP waveforms reflect post-synaptic (dendritic) potentials rather than axonal action potentials, since post-synaptic potentials have longer time constants than spikes of action potentials. Thus the time in which activation has to be synchronized can be longer [Rugg, 95]. The measured voltage differences are assumed to correspond to some psychological process. Thus, the sequence of perceptual and memory processes can be delineated (for overview see [Rugg, 95] [Fabiani, 00]). In this ERPs, combined with reaction times and error rates, provide the

basis for conclusions about the process of face recognition. The methodological framework is based on the assumptions made by the mental chronometry paradigm [Posner, 78] and cognitive psychophysiology [Donchin, 84]. Meyer, Osman, Irwin and Yantes [Meyer, 88] provide an introduction to the paradigm of mental chronometry. The rationale of mental chronometry is provided in terms of a basic stage model for human information processing [Donders, 69] [Sternberg, 69]. According to this model performance is a result of time-consuming processes, including perceptual encoding of a stimulus, retrieving of information stored in memory, making decisions about stored information and finally preparing an appropriate response. The underlying question is, whether information processing is really mediated by separable components and how they are temporally related. Are components of information processing serial or do they overlap and work in parallel? In contrast to serial processing stages the cascade model by McClelland [McClelland, 79] describes information processing in a parallel contingent way, with a continuous transmission of activation from one process to the next. Continuous information output to the next processing stage allowing the next process to overlap in time with the prior stage, would support the McClelland's [McClelland, 79] cascade model. Indeed some ERP evidence exists for the existence of parallel processing stages even in face recognition [Abdel Rahman, 02].

Within this thesis ERPs are related to the target faces onset and interpreted as indicators of separate stages of the face recognition process. Segments of the ERP waveforms vary in response to specific experimental manipulations. Components are amplitudes that can be defined in terms of peaks having characteristic polarity, latency (in ms), frequency and distribution across the scalp. A component can be quantified by voltage difference (in μV) measured either between peak point and baseline level (peak-to-base) or between peak-to-peak. Peak-to-peak amplitude measure refers to the voltage difference between a peak-point and a previous peak point of opposite polarity. Amplitude is further defined by frequency or an area measure respectively, integrating the voltage between two time points. ERP components can also be characterized by scalp distributions. Different scalp distributions indicate different spatial configuration of the current neural generators. However, it is difficult to determine the neuronal source from scalp distributions alone. This so-called "inverse" problem means that ERPs recorded from the scalp do not only reflect the activity of the brain regions immediately underneath the recording electrode.

This is due to the spread of electrical currents in the conducting media of the skull and scalp and to the orientation of the brain tissue [Rugg, 95]. Dipole modeling, applied to multi-channel recordings, reveals intra-cerebral locations that are estimated with respect to the temporal dynamics of their activation. In this thesis differences in neural activity as reflected by different topographies are analyzed to reveal differences in the underlying cognitive processing stages. Specific ERP components (for a review see [Schweinberger, 03]), namely the P100, N170, the early repetition effect (ERE) and the late repetition effect (LRE) are all related to the processing stages proposed by Bruce and Young [Bruce, 86c]. Some authors explore other probably face-specific potentials, for instance the vertex positive potential (VPP) at fronto-central electrodes first reported by Jeffreys [Jeffreys, 89]. Similar to N170, VPP occurs 150 to 200 ms after stimulus onset and seems to reflect an early visual stage of face processing in the fusiform gyrus that is stimulus related, sensitive to stimulus inversion and independent of familiarity [Itier, 02] [Rossion, 99a]. It is sometimes referred to as positive counterpart of N170 e.g. [Rossion, 03b].

1.4.2.1 P100

The earliest component detectable between 90-120 ms after onset of the visual target-stimulus is the P100 component and has been brought in line with visual spatial attention. The scalp distribution of the P100 (sometimes referred to as P1) component shows an occipital maximum, which may be consistent with a generator in the visual cortex probably in the striate and extra-striate areas [Heinze, 94] [Rugg, 95]. Using dipole-modeling Itier & Taylor [Itier, 02] detected a pair of dipoles in the parieto-occipital cortex and Schweinberger et al. [Schweinberger, 02b] located a dipole pair in lateral extrastriate areas. Mangun [Mangun, 95] and Rossion et al. [Rossion, 99a] report this early potential as sensitive to attention modulation that affects occipital visual areas triggered by the visual target-stimulus. P100 amplitude appears to be sensitive to physical variations in the stimuli used, like luminance, contrast or size [Pfütze, 02] [Itier, 02]. Furthermore a P100 increase in amplitude and latency was found for inverted faces [Linkenkaer-Hansen, 98] [Itier, 02] [Itier, 04a]. This could reflect the disruption of holistic processing or first order relations [Maurer, 02] by inversion, which disrupts the perception of a face as a face when the face is upside-down. There is relative agreement that the P100 is neither face-specific [Rossion, 99a] nor familiarity specific [Pfütze, 02]. [Rossion, 99a] [Schweinberger, 95] Yet, Engst, Martin-Loeches and Sommer [Engst, 06] found topographic differences of the P100

component to faces and buildings, even if the category-level was matched. This was ascribed to differences in low-level visual processing caused by spatial frequency content or height to width ratio of the presented stimuli. Only Schweinberger et al. [Schweinberger, 95] found a repetition priming effect in amplitude for unfamiliar faces, which disappeared when familiar and unfamiliar faces had been compared directly. In terms of the face recognition model by Bruce and Young [Bruce, 86c] results suggest a correspondence of the P100 to the level of viewer-centred descriptions including pictorial codes that in turn is assumed to be neither face nor familiarity specific.

1.4.2.2 N170

N170 is a negative component with a latency of 150 to 200 ms after target stimulus onset that responds maximally to face stimuli over temporo-parietal regions of the human scalp. The component may be generated in the region of the inferior temporal and occipital gyri, occipito-temporal sulcus [Bentin, 96] [Eimer, 00a] [Schweinberger, 02a]. Source analysis yielded a pair of dipols in the ventral pathway of the cortex and in the region of the fusiform gyrus [Itier, 02] [Schweinberger, 02b] [Deffke, 07]. Thus, N170 correlates with the face-selective N200, intracranially recorded by Allison et al. [Allison, 99] from the middle fusiform and posterior inferior temporal gyri. It is likely that N170 reflects early structural encoding and integration of sensory information into a unitary presentation. N170 is sensitive to changes in configuration of a stimulus, when faces are scrambled [George, 96], one or several features are removed [Bentin, 96] [Eimer, 98], features had been used only [Jemel, 99] [Taylor, 02], when faces are presented inverted e.g. [Itier, 02] [Schweinberger, 04] or presented inverted with single features turned upside down such as the "Thatcher-illusion" (see 1.2.2.3) as recently studied by Carbon, Schweinberger, Kaufmann & Leder [Carbon, 05]. When faces are embedded in gradually decreasing random noise levels [Jemel, 03c], or presented contrast reversed [Itier, 02], N170 amplitude increases and latency decreases corresponding to noise reduction. When faces are shown upside-down latency is delayed and amplitude of this component is increased [Eimer, 00a] [Eimer, 00b] [Itier, 02] [Itier, 04a] [Linkenkaer-Hansen, 98] [Rossion, 99a] [Schweinberger, 04]. Some authors found a latency shift but no differences in amplitude when faces were presented upside-down [Bentin, 96] [Eimer, 00a] [Eimer, 00b]. This sensitivity can be attributed to the increased difficulty in encoding a face. As processing of configural information is thought to be critical for structural encoding the

shift in latency shows that the structural encoding slows down due to the face-specific, configural information being disrupted by inversion [Leder, 00]. It was hypothesized that N170 relates to second-order relations, that is the spacing among facial features. Inverted faces hamper the perception of this configural aspect and may be processed instead, to a higher degree, on their isolated features [Maurer, 02]. Concerning the processing of separate features of the face, the eyes occupy an exceptional position [Schyns, 03]. When presented in isolation, eyes elicited an N170 that was larger than that elicited by the whole face, while nose or lips elicited a reduced and delayed N170 [Bentin, 96]. Based on a fMRI study by Haxby et al. [Haxby, 99] Rossion et al. [Rossion, 00a] attribute the inversion effect to brain regions that are involved when faces are presented inverted. Inverted faces utilize both brain areas that are specifically sensitive to faces and those areas generally involved in object recognition. Although it is accepted that N170 is very sensitive to faces, its specificity to faces is still controversially discussed [Carmel, 02] [Rossion, 02]. On one hand there are studies that found N170 evoked only by human faces and absent for other animal and non-face stimuli [Bentin, 96] and others that found N170 amplitude reduced for animal faces [Carmel, 02] [Schweinberger, 04]. On the other hand, there are studies that show N170 for printed words [Bentin, 99] [Schweinberger, 02a] [Pfütze, 02] and buildings [Engst, 06]. Itier and Taylor [Itier, 04b] differentiate between N1 for objects reflecting the return to baseline from P100 and N170 specific to faces, reflecting a supplement activity. Engst et al. [Engst, 06] found N170 topographies to differ clearly between faces and buildings, even when they matched category level between faces and buildings in this study. This suggests domain-specific neuro-cognitive modules. Furthermore N170 response to both faces and houses was found to be absent in a patient with apperceptive Prosopagnosia [Eimer, 99]. A more detailed result came from studies investigating category-specific lateralization. Most studies report N170 to be larger over the right hemisphere for faces e.g. [Bentin, 96] [Pfütze, 02] [Rossion, 03a] [Schweinberger, 04] [Yovel, 03]. Rossion et al. [Rossion, 03a] found N170 right lateralized specific to faces, left lateralized to words and bilateral for cars, this was reflected in scalp topographies and dipole source modeling. While locations were equivalent they differed in strength, orientation and lateralization. This indicates category specific information processing from 170 ms after target onset. The face-specificity of the inversion effect on N170 yielded different results and takes a center stage in the debate. Rossion et al. [Rossion, 00b]

compared the N170 and the inversion effect for faces, object categories (e.g. cars) and novel objects (Greebles). Greebles form a new category, but do share physical properties with faces such as, surface, symmetry, and configuration of individual features. Object categories, Greebles and faces elicited N170 and an effect after stimuli had been inverted in both categories, but the inversion effect for faces was specific in latency and amplitude. The authors attribute this to different levels of expertise between these categories. According to this subordinate-level theory it is the expertise that tunes the visual recognition system. In the case of face expertise the subordinate level represents individuality of face recognition. Supporting that, interference between dogs and face experts [Tanaka, 01b] or cars and face experts [Gauthier, 03] had been found, indicating similar mechanisms that are responsible for N170 response.
Concerning priming and familiarity effects on N170, results found have been somewhat inconsistent. While few studies demonstrate a familiarity specific priming effect on N170 e.g. [Caharel, 02] [Herzmann, 04] [Itier, 04a] [Kloth, 06], in other studies N170 was not affected by familiarity or priming e.g. [Bentin, 00] [Eimer, 00b] [Pfütze, 02] [Rossion, 99a] [Schweinberger, 02a] [Schweinberger, 02b].
Jemel et al. [Jemel, 03b] found priming effects when the physical parameter from the prime (normal photograph) to the target (Moony face) was changed, but only for familiar faces. The perceptual encoding of these impoverished facial images was enhanced due to a previous activation of the familiar face representation. This was reflected by a priming effect on the N170 amplitude showing smaller amplitude for repeated rather than unrepeated stimuli. The authors suggest that the N170 is likely to be modulated by top-down effects, which are required when a visual target is of low salience or ambiguous. This reinforces the hypothesis that perception is not “cognitively impenetrable” and supports the view, that cognitive influences might operate on the outcome of early visual processing because vision as a part of cognition is influenced by beliefs or utilities [Pylyshyn, 99]. Although, a priming effect on N170 was found for unfamiliar faces as well [Campanella, 00] [Itier, 02] [Schweinberger, 95], which challenges the top-down modulation hypothesis because internal representations for unfamiliar faces should not yet exist. These contradictory results could be due to the stimuli used, i.e. Mooney faces vs. gray scaled, to the number of intervening items, differences in ISIs, to the task (study-phase test-phase design; delayed same-different matching task) or to the applied

measurement.

Taken together there is some evidence to suggest that structural encoding can be influenced by priming and learning. The N170 reflects the structural encoding of a face pattern based on configuration aspects rather than the individual recognition of a face. Bruce & Young [Bruce, 86c] assume that the classification into basic level categories (e.g. dogs, houses, tables, faces) occurs as a part of the structural encoding component which is preparation for subsequent identification.

1.4.2.3 Early repetition effect (ERE)

Repetition priming of faces caused an ERP modulation at latencies from around 250 to 350 ms peaking around 300 ms. When measured against average reference this early repetition effect (ERE) is characterized by a fronto-central positivity and a negativity over inferior temporal electrodes for primed, relative to, unprimed faces [Barrett, 87] [Bentin, 94] [Boehm, 06a] [Pfütze, 02] [Schweinberger, 95] [Schweinberger, 02a] [Schweinberger, 02b] [Schweinberger, 04] [Trenner, 04]. There are few numbers of studies that have referred electrodes to CZ and that have lead to an opposite effect [Begleiter, 93] [Endl, 98]. The ERE is an ERP correlate of memory that is visualized as the difference between ERPs for repeated faces and faces presented for the first time. The effect has been variously termed. Begleiter, Porjesz, Wang and Zhang [Begleiter, 93] labeled this component as a "visual memory potential" that indexes STM in a delayed matching to a sample task. Within a repetition prime paradigm Schweinberger et al. [Schweinberger, 95], Pfütze et al. [Pfütze, 02] refer to it as "early repetition effect" (ERE) that is topographically dissociated from the "late repetition effect" (LRE) with a latency of 350 to 700 ms after target onset. The LRE will be closer defined in the next chapter. Moreover, Schweinberger et al. [Schweinberger, 02a] [Schweinberger, 02b] [Schweinberger, 04] labeled the effect ERE/N250r, which describes, specifically the inferior-temporal negativity in particular, elicited by **r**epeated as compared to unrepeated faces. The effect starts 250 ms after target onset. Still, later onsets had been reported as well [Jemel, 03a] and lateralization to the right hemisphere is not a consistent finding [Boehm, 06a]. Thus, within this thesis it is referred to as the early repetition effect (ERE).

Unlike the frontal activation, the inferior-temporal negativity has been brought into line with increasing reactivation of areas involved in face recognition and with the perceptual recognition of individual stimuli as a face-specific process. Fronto-central positivity might

reflect general working memory processes and explicit recollection that is not specific to faces. These complementary neural mechanisms might mediate the efficient recognition of familiar faces [Itier, 02] [Jiang, 00]. Dipole source analyses for the ERE revealed best fitting dipole-pairs located in inferior-temporal areas anterior to the location that has been found for N170 [Schweinberger, 02b]. This corresponds to locations that had been found by fMRI studies associated with repetition priming [Henson, 00] [Henson, 02] [Henson, 03] and face recognition [Kanwisher, 97] [Haxby, 00] namely to the ventral-temporal fusiform gyrus and to the lateral occipital face area [Schweinberger, 02b] [Schweinberger, 04]. The ERE is regarded as a correlate of access of stored representations of faces on a pre-semantic level, namely of the FRUs. Thus, the component constitutes the most relevant electrophysiological correlate of face recognition in this thesis. Still, it reflects short-term activation of perceptual representations, namely pictorial and structural codes, too. The amplitude and latency of ERE depends on experimental manipulations, concerning degree of familiarity, task, inversion or contrast reverse, and most important to changes in viewpoint. ERE to personal familiar faces was largest compared to famous people's faces suggesting stronger facial representations for people that are emotionally related [Herzmann, 04]. It was found to be smaller for indirect compared to direct tasks [Trenner, 04]. Inversion of faces and contrast reversed faces caused a delay and extension of the ERE amplitude [Itier, 04a]. Schweinberger et al. [Schweinberger, 04] found ERE to be absent when targets had been presented inverted.

Most importantly for the interpretation of this component as reflecting the activation of facial representations is its sensitivity to the type of priming, to familiarity, to number of intervening stimuli and SOA variations as well as to changes in viewpoint. Schweinberger et al. [Schweinberger, 95] studied effects of repetition and associative priming on performance and ERPs, relating the latter to different processing stages within the face recognition model by Bruce and Young [Bruce, 86c]. Schweinberger et al. [Schweinberger, 95] applied a repetition priming paradigm with immediate prime target sequences for both familiar and unfamiliar faces and found a strong frontal-temporal modulation with right hemispheric predominance between about 180-290 ms for both familiar and unfamiliar faces. The ERE for unfamiliar faces was smaller sized although still significant. This was also was found by Begleiter et al. [Begleiter, 95]. For both familiar and unfamiliar faces the early modulation dissociated from 180-220 to 230-290

and was clearly different from a later effect characterized by a centro-parietal maximum after 310 ms (LRE). In the associative priming condition the target face was preceded by a related familiar face, for example John Lennon primed by Paul McCartney. Here the early repetition effect was absent. Only the late repetition effect was found, which was topographically indistinguishable from the late effect found in the repetition priming condition. Thus, the late repetition effect was interpreted as reflecting variations in the processing of person-related semantic information that is also affected by visually derived semantic information (like gender or age) when the face is not familiar to the observer. The interpretation of the ERE was ambiguous because it was seen for familiar as well as unfamiliar faces. It was difficult to attribute it to only activation differences of FRUs. Even though, one could ask if face specific memories are formed after one initial encounter, the early effect for unfamiliar faces was ascribed to activations of visual representations of pictorial or structural type due to STM. Pictorial and structural codes are part of the perceptual based priming effect and are available for familiar as well unfamiliar faces and are able to affect repetition priming because of the immediate repetition. Henceforth "perceptual" is used to comprise both pictorial and structural encoding throughout). Thus, the ERE might be a conjunction of perceptual and representation based priming and can be interpreted at the perceptual level for unfamiliar faces as well as on the abstract representation level for familiar faces due to LTM in particular [Schweinberger, 95] [Pfütze, 02]. These results are in line with the theoretical account according to which repetition priming results from the activation of subsystems in the pre-semantic perceptual representation system [Magnussen, 00].

The studies by Pfütze et al. [Pfütze, 02] Herzmann [Herzmann, 04] and Boehm et al. [Boehm, 06a] have brought more light into the debate. Pfütze et al. [Pfütze, 02] disambiguated the interpretation of the ERE on the FRU level as all repetitions in their experiment followed several intervening unrelated face stimuli. Thus the repetition effect cannot be attributed to immediate repetitions and the repetition effect based on FRU activation should remain. Repetitions of familiar faces caused an ERE with a fronto-central maximum and a temporal minimum which resembles the effect found by Schweinberger et al. [Schweinberger, 95]. But most importantly the ERE was absent for unfamiliar faces and clearly reduced and delayed in latency for familiar faces. Thus, the very early part of the repetition effect irrespective of familiarity found by Schweinberger et al. [Schweinberger,

95] was due to the short-term activation of perceptual codes. The ERE for unfamiliar faces could be eliminated in the study by Pfütze et al. [Pfütze, 02] retaining residual activation due to representation based face priming as indicating LTM. This was supported by Herzmann et al. [Herzmann, 04, who found an ERE for unfamiliar faces that was topographically distinguishable from both familiar and famous faces. Boehm et al. [Boehm, 06a] investigated perceptual contributions of face priming by disrupting perceptual processing of faces when the initial presentation of a familiar face was inverted and the delay from prime to target was filled with one to three different faces. The ERE was smaller for inverted, as compared to upright familiar faces concerning the initial presentation and absent to unfamiliar faces in the inverted condition. The magnitude of the difference between the EREs for familiar faces when initially presented upright or inverted corresponded with the ERE found for unfamiliar faces in the upright condition, reflecting the contribution of perceptual face priming for representation-based face priming due to non-declarative memory. As face inversion causes a disruption of configural processing, the authors conclude that perceptual face processing relies primary on processing second-order-relations (distances and angles between eyes, nose and mouth; Maurer et al., [Maurer, 02]) as a type of configural processing. Thus when perceptual-based priming is eliminated in terms of the model by Bruce and Young [Bruce, 86c] the ERE reflects activation of FRUs and following the network model by Burton et al. [Burton, 90] strengthened links between feature units and FRUs and FRUs and PINs. Joyce and Kutas [Joyce, 05], Schweinberger et al. [Schweinberger, 02a] and Trenner et al. [Trenner, 04] investigated ERP correlates of repetition priming over longer time intervals (15 minutes, one hour, one day, one week) and in situations in which many more faces (hundreds) intervene between repetitions. For long SOAs (15 minutes) a modulation at inferior-temporal sites was no longer found anymore e.g. [Schweinberger, 02a]. Joyce and Kutas [Joyce, 05] found an ERE after a one hour delay between repetition, but not thereafter. That suggests that the ERE is insensitive to repetition priming across longer time intervals and reflects a fast decay of the iconic memory trace. Instead, repetition priming caused a priming effect with parietal-central positivity similar to the late effect found by Schweinberger et al. [Schweinberger, 95] and Pfütze et al. [Pfütze, 02]. Results support the idea that changes at the level of FRU activation are very transient and thus can only explain intermediate (only a few seconds and intervening stimuli) face priming. Long-

lasting priming effects might instead caused primarily by a strengthening of the connections of perceptual nodes to post-perceptual memory nodes (FRU to PIN, access to semantic information).[6]

The ERE was demonstrated to be sensitive to image changes [Schweinberger, 02b] Using a prime- target paradigm, without masking the prime, the ERE was still significant across image changes but reduced in amplitude. As this contradicts Bruce and Young [Bruce, 86c] who conceptualised FRUs as image-independent representations, Schweinberger et al. (2002 b) concluded that the ERE might signify the stimulus-triggered access to stored facial representations but not the activation of FRUs itself. Yet, the paradigm used by Schweinberger et al. [Schweinberger, 02b] was an immediate prime-target paradigm. Thus the difference of the EREs after repetition of the same versus different view might be due to the contribution of perceptual-based priming in the view-same condition. When the image changed between the first and the second presentation, the perceptual code changes up to a certain degree, what decreases perceptual-based priming. Thus, a smaller sized ERE might be biased by different contributions of perceptual-based and representational-based priming in the view-same and the view-different conditions. Moreover, images from famous people had been used, which implies the previous storage of many different views. In consequence to that, conclusions about the characteristics of facial representations in memory are hindered. If the ERE would indicate the access of facial representations in the image-same condition exclusively the question about their sensitivity to changes in viewpoint might be answered more satisfactorily.

Jemel et al. [Jemel, 03a] reported that the ERE disappeared when images had been changed from the first to the second encounter and conclude that it only reflects episodic memory rather than long-term representations of faces in the sense of FRUs. Yet, the authors used a continuous performance paradigm with up to 30 intervening items between prime and target and propose that the ERE could reflect the viewpoint-dependent property of FRUs rather than simply episodic memory activation.

[6] The idea that priming causes changes in the links between representations is widely accepted in word and object recognition as well [Vitkovitch, 91] [Wheeldon, 92].

At the time of writing and to my knowledge an ERP study, investigating the EREs sensitivity to standardized view-changes rather than image changes has not been conducted (see also 1.3.4, *Table 1*). There are differing results concerning domain-specificity of the ERE component. It was also observed for names of celebrities [Pfütze, 02] [Pickering, 03], but with a different scalp distribution (left preponderant – as a trend – for names) indicating domain-specificity. Schweinberger, et al. [Schweinberger, 04] found ERE largest for human faces, reduced for ape faces and absent for cars. Martin-Loeches, Sommer & Hinojosa [Martin-Loeches, 05] compared faces, person names, common objects and object names. ERE differences in amplitude and topography in all stimuli classes were found, but only for object names was the ERE absent. Though this finding suggests domain-specificity for access to stored knowledge of a stimulus class, Engst et al. [Engst, 06] could not reconfirm the topographic difference, when buildings and faces of the same category level had been compared. This indicates common or at least overlapping storage of structural representations of the face and the building domain.
To summarize, existing data supports the idea that the ERE originates from a representation based and a perceptual-based locus. The first locus refers to changes in activation thresholds of stored representations of faces previously activated in the FRUs and is of most interest here. When perceptual short-term contributions are eliminated, it is possible to draw conclusions about viewpoint-dependency of facial representations and thus, the way in which faces are stored in LTM.

1.4.2.4 Late repetition effect (LRE)

In the time range from 300 to 700 ms repetition as well as associative priming for familiar and unfamiliar faces yielded an enhanced positivity at centro-parietal electrodes and an enhanced negativity at frontal electrodes for repeated faces [Barrett, 87] [Bentin, 94] [Pfütze, 02] [Schweinberger, 95] [Schweinberger, 02a]. The late modulation of the repetition effect was topographically dissociable from the ERE modulation, indicating a different processing stage in contrast to the preceding perceptual processing stage. Moreover, associative priming did not affect earlier components like N170 or ERE. Thus, there is relative agreement that the late component reflects facilitation in assessing post-perceptual or semantic memory codes for a repeated encounter in relation to the initial encounter of people's faces on the level of PINs [Bruce, 86c] or semantic information units [Burton, 90]. In the present thesis this late repetition effect will be referred to as LRE,

although often labeled as LRE/N400 [Boehm, 06a] [Engst, 06] [Schweinberger, 03] [Trenner, 04] for the following reasons. As the scalp distribution of the late repetition effect was related to similar N400 effects e.g. [Bentin, 94] and old-new effects e.g. [Paller, 99] [Paller, 00] [Paller, 03b] the LRE is thought to be a modulation of the N400 component. The enhanced negativity at frontal electrodes to familiar and unfamiliar faces caused by associative and repetition priming, was initially demonstrated to reflect detection of semantic incongruence in sentences, being larger the less predictable a word is and for that reason related to semantic integration [Kutas, 00] [Kutas, 80]. Bentin & McCarthy [Bentin, 94] investigated immediate repetition priming for words and faces within tasks of different complexity, requiring different depths of processing. Repetition priming was found in all tasks and independent from stimuli type. But, ERPs were strongly affected in tasks where long stimuli analysis was necessary to deduce the correct decision about a stimulus, as in a lexical decision task. Repetition priming caused an enhancement in P300 amplitude and reduction of its latency. But most notably a negative component was attenuated that was related to N400 reported by Kutas and Hillyard [Kutas, 80]. Bentin & McCarthy [Bentin, 94] hypothesized that N400 reflects access to the semantic structure since it was absent in discrimination tasks that could be performed on the gross physical features of the stimuli without reference to their meaning. When the task requires a decision based on semantic information about the stimulus that is repeated immediately, N400 increase reflects facilitated stimulus identification based on easier access to previously activated semantic memory whilst making categorical decisions [Bentin, 94]. Schweinberger [Schweinberger, 96], Pickering and Schweinberger [Pickering, 03] demonstrated domain-independence of the late repetition effect for names and faces. Associative priming caused an N400-like modulation equivalent for within-domain (related face-face) and cross-domain (related name – face) conditions. Indistinguishable topographies for faces and name targets suggest the same underlying brain source that generates the priming effect [Schweinberger, 96] [Pfütze, 02]. fMRI studies on semantic processing of faces indicate brain generators similar to N400 found for language stimuli, namely in anterior ventral temporal lobe regions [McCarthy, 95]. Moreover, even degradation of the target stimulus did not affect the late time segments related to associative priming. Therefore, associative priming in person recognition proceeds on a post-perceptual locus, and acts on domain-independent representations of a person's

identity (PINs).

In a repetition priming paradigm the LRE between 300 and 500 ms was observed for unfamiliar faces as well. The LRE for unfamiliar faces was reduced in amplitude [Bentin, 00] [Eimer, 00b] but topographically indistinguishable from the negativity found for familiar faces [Pfütze, 02] [Schweinberger, 95]. Thus the LRE is not only related to activation of person specific semantic information but is also related to PIN activation. It also reflects facilitation of processing of visually derived semantic information like age or gender (Schweinberger et al. 1995). The LRE is absent when unfamiliar faces are presented inverted in the second encounter [Eimer, 00b] [Itier, 04a]. Thus the visual derivation of semantic information is interrupted.

A different interpretation of the LRE is provided by Jemel et al. [Jemel, 03a]. The authors found the component to be insensitive to view changes from the first to the second presentation while the early repetition effect disappeared, when up to 30 items intervened prime and target. Thus, the authors associated only the LRE with the degree of activation of memory representational system for faces (FRUs). Schweinberger et al. [Schweinberger, 02b] found the LRE to be insensitive to viewpoint changes as well.

Paller et al. [Paller, 00] demonstrated that the amount of semantic information (named face versus unnamed face) given in the study face affects ERP during recognition in the test phase. In general, potentials to old faces were more positive than to new faces from 300 to 600 ms after face onset, this was labeled as old/new effect (see 1.4.1.1). But, for named faces the old/new ERP difference occurred at anterior and posterior scalp locations, whereas for unnamed faces only a posterior old-new difference was found. Therefore Paller et al. [Paller, 00] interpreted the posterior part of the effect as related to retrieval of visual information and the anterior part of the effect as related to the retrieval of person-specific semantic information. This is in line with the processes that are associated with the N400 as outlined above. An fMRI study by Paller et al. [Paller, 03b] revealed the reactivation of a distributed neural network including left hippocampus, left middle temporal gyrus, left insula and bilateral cerebellum that is associated with the old/new effect. This corresponds to other studies that have identified brain regions particular in the left hemisphere that play a critical role in semantic memory for objects, including the temporal lobes and the left prefrontal cortex, that might play a general role in retrieving lexical and semantic information [Martin, 01]. Engst et al. [Engst, 06] found topographic

differences in the LRE when buildings and faces are recognized suggesting at least partially different underlying sources.
In summary the LRE is thought to reflect facilitation of the access of post perceptual semantic memory codes as stored in PINs [Bruce, 86c] or semantic information units [Burton, 90] of person specific, as well as, visual derivable information.

1.5 Purposes and rationale of the thesis

The focus of this thesis is two-fold: The first purpose is the extraction of an ERE that reflects representation-based repetition priming and thus signals the activation of facial representations. The second purpose is based on the first and looks at the sensitivity of the facial representations as reflected by the ERE concerning changes in viewpoint from the first to the second encounter with a face. This allows conclusions to be made about the way in which facial representations are stored in memory with respect to content and dimension. The question posed is whether, faces stored by viewpoint-invariant, three-dimensional analogues of the faces they represent, where features are related not to the viewer but to the face itself and thus, can be described as object-centred, or, are they stored by a series of two-dimensional snapshots, depending on the position of the viewer relative to the face being recognized?
The following provides the reader with the main questions and hypothesis of the present thesis. A synopsis of the accomplished experiments and the coding of the conditions in particular are given in *Table 2* at the end of this section. A detailed description of the hypotheses, per experiment, is given at the beginning of the experimental parts. The following measures in dependency of experimental condition are consulted: reaction times (RT), percentage of errors (PE), ERPs, the ERE (latency, amplitude and topography) being of main interest.

1.5.1 The ERE as a marker of facial representations stored in memory

Models of face recognition [Bruce, 86c] [Burton, 90] postulate a processing stage where structural representations of familiar faces stored within so-called FRUs are accessed (see *Figure 1* in 1.2.1.1). Previous studies [Pfütze, 02] [Schweinberger, 95] suggested the existence of a component in the ERP which signals activation of stored representations of faces known to the observer, the ERE. When familiar faces are shown repeatedly, the ERE around 250-350 ms is more positive at fronto-central and more negative at occipito-

temporal sites for the second presentation. Taken altogether, the results by Schweinberger et al. [Schweinberger, 95] Pfütze et al. [Pfütze, 02] and Boehm et al. [Boehm, 06a] [Boehm, 06b] show that the ERE originates from two dissociable processes, the facilitated access to preexisting representations of familiar people and facilitation in perceptual processing for both, familiar and unfamiliar faces (see 1.4.2.3). Thus, the first purpose of this thesis is to validate the ERE as primarily reflecting the activity of pre-semantic facial representations. In Experiment I and II a repetition priming paradigm with backward masking was tested to impede perceptual-based priming and to maintain representation-based priming when the target face is recognized. The details of the paradigm are schematically presented in a working model shown in *Figure 4*.

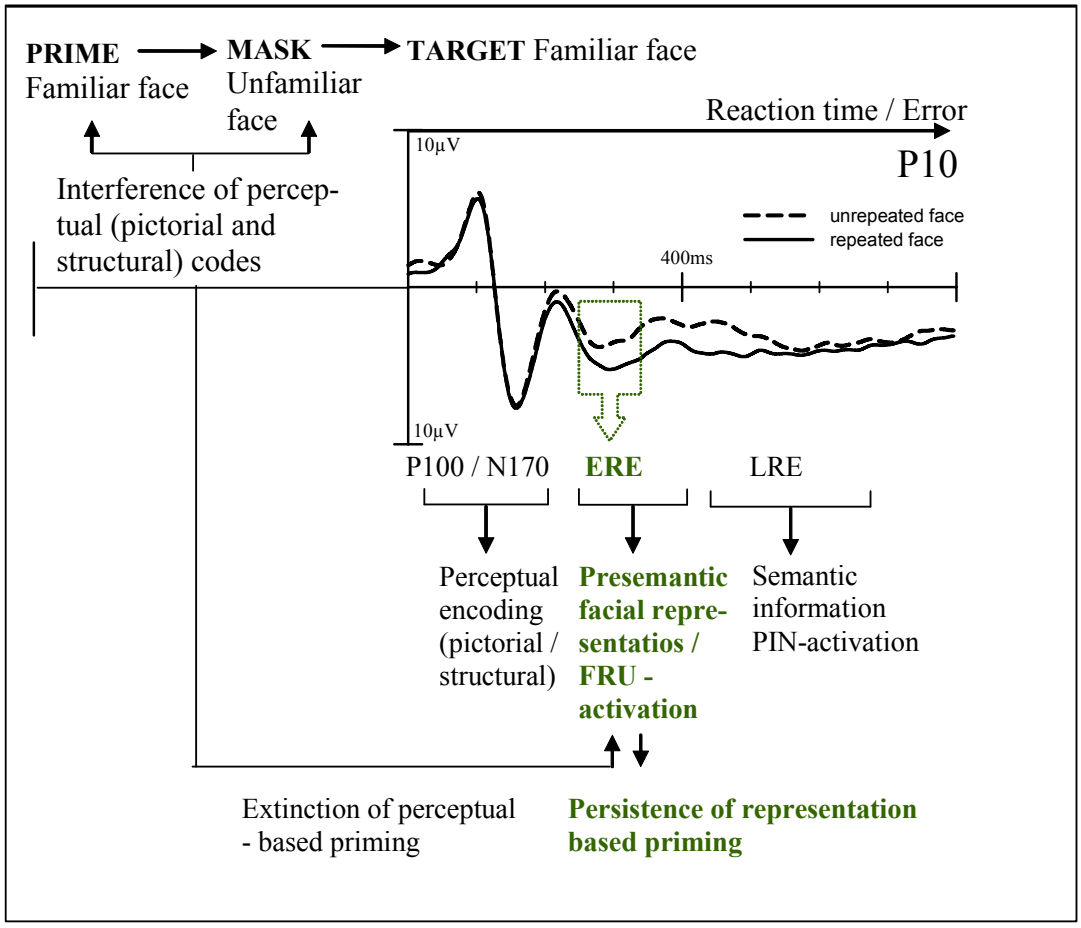


Figure 4: *Working model on which the experiments are based (repeated / unrepeated is synonymous with primed / unprimed)*

Perceptual (structural and pictorial) codes are masked by insertion of an unfamiliar face back-to-back to the prime face. Perceptual priming process should be impeded while the representation-based priming process should persist and the ERE should be confined to

familiar faces. The foregoing components, P100 and N170, have been brought in line with perceptual encoding processes rather than activation of representations of a stimulus already stored in memory. Thus, neither priming nor familiarity, nor the type of the mask should affect these components.

In contrast the LRE should be affected by priming as well as familiarity. Experiment I compares the impact of a facial mask that follows the prime on the repetition of familiar and unfamiliar faces. Provided that the unfamiliar face mask impedes perceptual-based priming, the ERE is expected to be detectable for familiar faces only. Experiment II is designed to specify the impact of different mask types (grey rectangle, scrambled face and face mask) on different levels of processing of the prime face. Itcan be expected that the ERE to the target face would be affected in the following ways: The grey rectangle does not resemble the face stimuli either pictorially, or concerning structural codes. Hence no mask effect is expected and thus, the largest ERE amplitude compared to the scrambled face and face mask condition is expected. As a scrambled face mask con-tains a similar pictorial code as the prime face, it interferes with the pictorial code of the prime face and impedes its further processing, but because of the lack of structural information in the scrambled mask structural codes of the prime should persist between the presentations. The familiar face mask resembles the prime face in both its pictorial and structural codes. It interferes with both of the perceptual codes of the prime impeding its further processing. Thus, a scrambled face mask should yield a mid-sized ERE while the smallest ERE is hypothesized for facial masks.
If there is a familiarity specific ERE (Experiment I) and a systematic increase across the three mask conditions, demonstrating contributions of perceptual codes (Experiment II) repetition priming with backward masking with unfamiliar faces can be considered as a suitable tool to obtain ERE that indicates FRU activation and thus, retrieval of facial representations. Based on these results the second purpose focuses on the viewpoint-dependency of the ERE and of representations of faces in memory.

1.5.2 Viewpoint-dependence of representation-based face priming: properties of the ERE

According to Bruce and Young [Bruce, 86c] FRUs contain an interlinked set of structural codes for distinct head angles including codes reflecting the global configuration and others that represent features, which become active after any view of a familiar face is seen. In that sense they can be characterized as being viewpoint-independent and object-centred without being a three-dimensional holistic representation [Burton, 94] [Tanaka, 93]. There are different theories about the representation of objects and faces in LTM with respect to dimension and the kind of information that is stored: within object-centred, three-dimensional parts [Biederman, 87] or images [Moses, 96] [Ullman, 89] that afford viewpoint-invariant recognition on a basic-category level (therefore less able to account for individual face recognition) or within viewer-centred, two-dimensional representations by means of multiple stored views and their interpolation [Bülthoff, 92] [Poggio, 90] [Tarr, 89] [Ullman, 91]. Previous studies (see 1.3.4; *Table 1*) demonstrated viewpoint-dependent as well as viewpoint-invariant recognition with respect to accuracy. Therefore, the most suitable model of object and face recognition within a rather homologous stimulus class should incorporate aspects of theories predicting viewpoint-invariance and those that postulate viewpoint-dependence [Tarr, 98a]. [O'Toole, 98] and Valentin and colleagues [Valentin, 97] [Valentin, 99] [Valentin, 01]demonstrated recognition performance, with respect to accuracy, to be still above chance level even under extreme viewpoint changes. The authors suggested that face recognition across changes in viewpoint, with respect to the learned view up to 30°, is based on distinct aspects of configuration as revealed by the whole image and from 40° to 90° on features, that are extracted as two-dimensional representations from a single point of view that distinguish one face from all other faces. Thus the storage of configuration or features in memory depends on the angel of view change with respect to the learned view. In Experiment III of the present thesis the question of viewpoint-dependence of facial representations is addressed by exploring the EREs dependence of view changes from a single familiar (frontal or profile) to an unfamiliar (profile or frontal) view and towards the learning view.

Table2: Accomplished experiments, conditions and nomenclature

Experiment I		Experiment II		Experiment III / recognition session 1: viewpoint dependence		Experiment III / recognition session 2: familiar specificity	
Nomenclature Character 1: Familiarity of target Character 2: Familiarity of prime Character 3: Type of prime (familiarity in the sense of famousness)		Nomenclature 1st characters: Type of mask last character: Type of prime (primes and targets always familiar; familiarity in the sense of famousness)		Nomenclature Character 1: View of target Character 2: View of prime with respect to target view Character 3: Type of prime (targets always familiar, in the sense of newly learned)		Nomenclature Character 1: View of target Character 2: Familiarity of target Character 3: Type of prime (familiarity in the sense of newly learned)	
FFP	familiar -familiar -primed	FACE-P	face mask – primed	FSP	frontal – same - primed	FFP	frontal - familiar - primed
FUU	familiar – unfamiliar – unprimed (incongruent)	FACE-U	face mask – unprimed	FSU	frontal – same – unprimed	FFU	frontal - familiar - unprimed
FFU	familiar – familiar - unprimed (congruent)	SCRA-P	scrambled mask - primed	FCP	frontal – changed - primed	FUP	frontal - unfamiliar - primed
UUP	unfamiliar – unfamiliar – primed	SCRA-U	scrambled mask – unprimed	FCU	frontal – changed - unprimed	FUU	frontal - unfamiliar - unprimed
UFU	unfamiliar – familiar – unprimed (incongruent)	NON-P	non mask – primed	PSP	profile - same - primed	PFP	profile - familiar - primed
UUU	unfamiliar – unfamiliar – unprimed (congruent)	NON-U	non mask – unprimed	PSU	profile - same - unprimed	PFU	profile - familiar - unprimed
				PCP	profile - changed - primed	PUP	profile - unfamiliar - primed
				PCU	profile - changed– unprimed	PUU	profile - unfamiliar - unprimed

A total of 64 faces, 32 from the frontal and 32 from the profile view, were learned prior to the experiment. The latency, amplitude and topography of the ERE would reveal valuable information with respect to the comparison of view changes below 30° that is associated with recognition by configuration and of view changes above 40° which involves recognition by features e.g. [O'Toole, 98] [Valentin, 01].Repetition priming with backward masking using an unfamiliar face mask (as tested in Experiment I and II) was used to extract an ERE as a marker of representation-based face-priming. Experiment III was composed of two parts: Recognition session 1 was to test view-dependence of the ERE. Recognition session 2 was to analyse the ERE with respect to its specificity to learned stimuli. Within both parts the EREs were compared with respect to the learning views. Following the idea of FRUs by Bruce & Young [Bruce, 86c] and based on the accounts by O'Toole et al. [O'Toole, 98] and Valentin et al. e.g. [Valentin, 01] the following is hypothesized: When faces are primed with the same or the changed view (frontal to profile or profile to frontal) an ERE is predicted, but its amplitude should be relatively small in the view change condition. Meaning that, the encounter with a single view of a face is sufficient to recognize a face from an extremely different viewpoint. The attenuation of repetition priming across different images was also predicted by Burton et al. [Burton, 99] within the IAC model (see 1.2.1.2.2). As the configuration by means of the distances among facial features is susceptible to view changes, face recognition across extreme changes in viewpoint (40-90°) might be based on features that are still visible after view change rather than relying on facial configuration or images. That would be compatible with theories that assume face recognition as encoding of both feature-based, as well as configuration-based information e.g. [O'Toole, 98]. Theories that rely on multiple views of two-dimensional images and their interpolation alone [Bülthoff, 92] might have to be rejected as at least two different views have to be encountered before face recognition is possible from an unfamiliar point of view. Moreover, a view change of this magnitude will impede the transformation process as substantial portions of the face will not be visible in the unfamiliar view. An ERE which is topographically indistinguishable with respect to the same or changed viewpoint and to learning view would support the idea of consolidation of features and configuration according to different views into a single representation – FRUs - and in that sense towards viewpoint-independence in face

recognition. This would also reconcile the assumption of the integration of several view-dependent images [Bülthoff, 95] [Schyns, 93] and features [Schwaninger, 02] into a single representation. The results of the present thesis will not give a definitive answer of whether facial representations resemble object-centred, three-dimensional representations rather than viewer-centred, two-dimensional representations, because of an interaction with expertise with the stimulus material. Still, they will provide a step in this direction.

2 REPETITION PRIMING WITH BACKWARD MASKING: THE ERE AS A MARKER OF FACIAL REPRESENTATIONS STORED IN MEMORY

2.1 Experiment I

2.1.1 Objective and hypotheses

The objective of Experiment I was to find a paradigm that would enable the exploration of the viewpoint-dependency of FRUs by demonstrating an ERE that is based on the activation of stored representations. For this purpose the paradigms from Schweinberger et al. [Schweinberger, 95] and Pfütze et al. [Pfütze, 02] were combined. Schweinberger et al. [Schweinberger, 95] used an immediate repetition priming paradigm. Prime and target faces were immediately repeated with a grey rectangle shown between them. They found an ERE for familiar faces, but also one for unfamiliar faces that was smaller in amplitude but similar in topography. A possible explanation for these priming effects is that repetition priming results from two dissociable processes: the facilitated access to pre-existing representations of familiar faces in LTM and the facilitated perceptual processing due to STM. When multiple faces intersperse the prime target sequence the perceptual codes might be extinguished between representations, and visual short- term priming disrupted. This was realized by Pfütze et al. [Pfütze, 02] within a continuous performance paradigm. When two to four faces where inserted between the repetition of a familiar or unfamiliar target face, the ERE was confined to familiar faces but was generally rather small. With Experiment I a prime-target-combination with backward-masking was tested. An unfamiliar face interspersed the prime target sequence in order to extinguish superimposed visual short-term priming to the ERE. With respect to the stimuli and the familiarity decision task Experiment I is comparable to the experiments by Schweinberger et al. [Schweinberger, 95] and Pfütze et al. [Pfütze, 02]. Furthermore the same trial schema, ISI and SOA, was used as in Schweinberger et al. [Schweinberger, 95] apart from the intervening face mask. Concerning that Experiment I was a replication of the study by Schweinberger et al. [Schweinberger, 95].

Hypotheses were as follows:

1. Because Pfütze et al. [Pfütze, 02] found a repetition priming effect in RTs for unfamiliar faces, a priming effect in RTs should be seen for familiar as well as

unfamiliar faces. In general RTs to familiar faces should be smaller compared to unfamiliar faces.

2. In ERPs a repetition priming effect starting about 200 ms until the end of the recording epoch that is smaller or even absent for unfamiliar faces was hypothesised. No repetition priming effects were expected for P100 and N170. The repetition effect should include two topographically distinguishable parts over time, according to the ERE and the LRE.
3. When familiar faces are primed, the ERP around 300 ms is more positive at fronto-central and more negative at occipito-temporal sites for the second presentation. This earlier modulation can be extracted from a general repetition priming effect (from 200 ms onwards) as hypothesised and labeled with ERE (see 1.4.2.3).
4. The other subsequent topographically distinguishable part of the repetition effect is the LRE (see 1.4.2.4) showing the semantic component of face recognition and thus, subordinately important for the present purposes. The LRE shows a central positivity and a prefrontal negativity. Due to the visually derivable semantic information (e.g. age, attractiveness) it should be found for unfamiliar faces as well [Schweinberger, 95].
5. The familiarity specific priming effect should, because of the adapted paradigm that was used, be smaller compared to that found by Schweinberger et al [Schweinberger, 95] and larger compared to Pfütze et al. [Pfütze, 02].
6. Pfütze et al. [Pfütze, 02], as well as Schweinberger et al. [Schweinberger, 95] found the ERE to be more pronounced on the right hemisphere. Still, lateralisation was not a consistent finding [Boehm, 06a] and see 1.1.2.2. Hemispheric differences are analyzed for the time segment where the ERE and the preceding ERPs, P100 and N170, are determined.
7. For the comparison of the two unprimed conditions for familiar and unfamiliar faces separately (see 2.1.2.3) no differences are expected as seen in the previous results by Schweinberger et al. [Schweinberger, 95].

The seventh hypothesis refers to the following: For experimental reasons one primed condition and two different unprimed conditions for familiar and unfamiliar target faces

each had been implemented, it is possible to analyse side effects concerning differences in the unprimed conditions per familiarity, and use them to control priming effects in the subsequent experiments.

2.1.2 Methods

2.1.2.1 Participants

Experiment I involved 19 participants, but, because of technical problems in data acquisition, three participants had to be excluded. Therefore, the data of 16 participants, 12 women and 4 men, were included in data analyses. All were aged between 20 to 32 years, M = 26.37 years (SD = 3.85). Handedness was tested by a German version of the Edinburgh inventory [Oldfield, 71]. All participants were strongly right-handed (index of handedness < 60) and had normal or corrected-to-normal visual acuity. One week before the experiment participants answered a questionnaire to determine whether they would be able to identify a celebrity's face by name. It contained 128 items and names of celebrities respectively and had to be completed one week before the experiment. People who failed to recognize at least 80% of the celebrities listed in the questionnaire were excluded. The questionnaire and the list of the names respectively are shown in Appendix D. Appendix D comprises the questionnaire used in Experiment I and reused in Experiment II, apart from additional stimuli used in Experiment II. Names labelled with "I / II" are used in both experiments.

2.1.2.2 Stimuli and Apparatus

The stimuli used were black-and-white portrait photographs of familiar people from various areas (e.g. politics, entertainment, sports; see Appendix C) and of unfamiliar people chosen to resemble the familiar faces as close as possible with respect to approximate age, gender and general portrait style. As familiar target faces 87 men and 41 women were presented to each participant. Both familiar and unfamiliar faces that were used as the prime, mask or target had been provided by courtesy of Dr. Eva Pfütze, by the Department of Psychology at the University of Glasgow and by PhD Walter Endl [Endl, 98]. All stimuli were software-edited using Adobe Photoshop™ and converted to 256 levels of grey. They covered 102 x 125 pixels corresponding to a stimulus size of 3.6 x 4.4 cm and a visual angle of 2.56° horizontal by 3.14° vertical at the viewing distance of 80 cm. Stimuli were displayed on a 17 inch monitor. In difference to the original copies of the other face

stimuli (Dr. Eva Pfütze) [Endl, 98] the background of the face stimuli from the University of Glasgow was replaced by a black background (for examples see Appendix C). Accordingly the stimuli were presented block wise during the experiment. ERTS© (BeriSoft Cooperation; [Dutta, 95]) served as the experimental software for stimulus presentation and response recording. The stimuli were homogenized with respect to luminance and contrast. Mean luminance *M* = 780 Lux (SD = 106 Lux) was the same for familiar and unfamiliar stimuli.

Celebrities were selected on the basis of familiarity ratings of all the portrait photographs available from different sources described above. Prior to Experiment I the portraits (see Appendix C) had been shown to 9 people living in Berlin aged between 20 to 35 years. They had to decide whether the face is familiar to them or not, and in case of familiarity had been asked to give some semantic details about this person (e.g. actor, politician, athlete) and how sure they are about the answer (0 = not at all; 1 = perhaps; 2 = sure). Only the faces mostly rated as "sure" familiar were included in a set of 116 familiar faces and included in the questionnaire (128 familiar faces) to be answered by the participants of Experiment I. Both familiar and unfamiliar faces were further subdivided into six sets of 18 faces and assigned to blocks of 36 trials. The remaining 20 familiar faces had been used in practise trials. Types of stimuli (from Glasgow or Berlin) were separated by blocks. The assignment to the experimental condition (primed, unprimed see *Table 2*) was counterbalanced in respect to gender.

2.1.2.3 Procedure

The experiment was conducted in a dimly lit, sound-attenuated and electrically shielded chamber. Participants received written task instructions on a computer screen. For the exact wording of the instructions see Appendix F. Two response keys were fixed 4 cm apart from each other left and right from the participant's saggital midline. The assignment of the right or left index finger to single stimuli was reversed for half of the participants. Participants were shown sequences of three faces and decided by two-choice key presses whether the third face (target stimulus) represented a famous (i.e. publicly known) or an unfamiliar person. They were asked to respond as quickly and accurately as possible. There was no clue offered concerning the relation of the target face to the prime face (1st face). Participants received feedback to correct, incorrect, late or missing responses while

responding to practise trials, which was indicated by the phrases “richtig”, “falsch” or “zu langsam” on the computer screen. During trials only too slow (RT larger than 1500 ms) or missing responses were indicated on the computer screen. Participants were instructed to blink only when the fixation cross was seen.
Each trial started with a fixation cross, followed after 200 ms by the prime stimulus. The prime was shown for 500 ms and was terminated by a face mask of the same size and luminance, presented as long as the prime stimulus, for 500 ms. Between mask and target there was a 790 ms-ISI, by that time a grey frame sized as the stimuli was shown. The target face was presented 1.790 ms after prime onset and remained on the screen for 1250 ms or it was terminated by the answer or the feedback “too slow”. By the end of each trial the same grey rectangle as used before appeared. The inter-trial interval between prime stimulus onsets was 6.000 ms (see *Figure* 5).

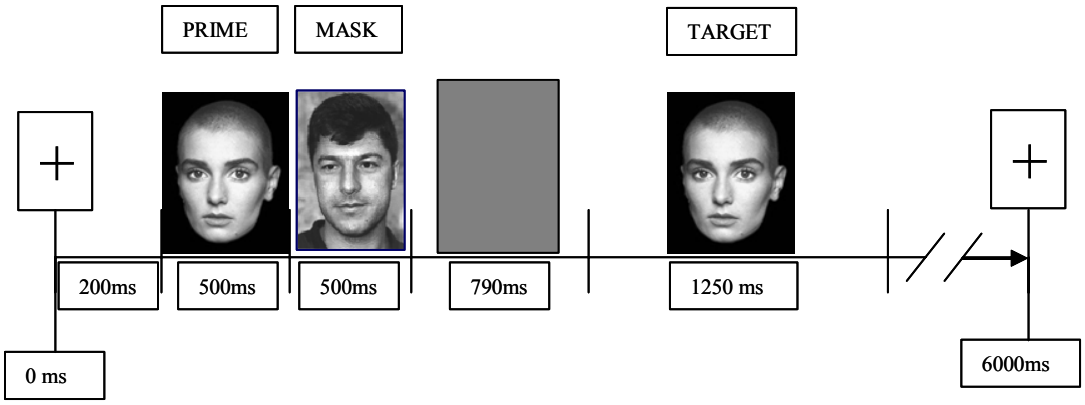


Figure 5: *Trial sequence Experiement I, II, III (for mask types see Experiment II)*

A total of 216 prime-mask-target-sequences had been shown. Short breaks were allowed after 40 trials each. The assignment to the response keys was reversed after 108 trials. In addition 27 practise trials were conducted twice, once at the beginning of the experiment and then after the assignment to the response keys were changed. In addition 4 practise trials preceded the 36 trials at the beginning of each block. Practise trials were not subsequently used. This experiment was designed to compare responses to familiar target faces with responses to unfamiliar target faces preceded by three kinds of primes:

A) Identical prime, target face was a repetition of the prime face (FFP, UUP)

B) Different familiar face in the unprimed condition (FFU, UFU)

C) Unfamiliar face in the unprimed condition (FUU, UUU)

The nomenclature of the six conditions is indicated in brackets and explained in the synopsis of the accomplished experiments in *Table 2* (see 1.5.2; p. 77). Further on I will refer to those unprimed conditions with a changed familiarity from prime to target as incongruent (FUU, UFU) and those with unchanged familiarity as congruent (UUU, FFU). The six conditions and all trials respectively were presented in a randomized order to eliminate any predictive value of the prime type for the target stimulus. Thus, both familiar and unfamiliar primes were equiprobable and were equally likely to be followed by the same or a different familiar or unfamiliar target. Still, when collapsing primed and unprimed congruent conditions, the prime was more likely to be followed by a target whose familiarity was congruent to the prime. To eliminate the predictive value of the familiarity of the prime to the familiarity of the target, the number of unprimed incongruent conditions would have had to be doubled. Due to the limited amount of stimuli this was not possible. Target faces appeared only once as targets and were reused as primes in the conditions B, C, in the second part of the experiment, after the assignment to response keys changed. Thus, in the unprimed condition a given pair of faces was used only once in order to avoid episodic priming. The unfamiliar face mask was different in each trial.

2.1.2.4 Performance

Responses were scored as correct if the appropriate key was pressed within a time window lasting from 100 to 1500 ms. Errors of omission (no key press) and commission were recorded separately. Mean RTs were calculated for correct responses only.

2.1.2.5 EEG-recording

The EEG was recorded with tin electrodes mounted in an electrode cap (Electro-Cap International, Eaton, OH) at 28 scalp positions Fz, Cz, Pz, Iz, Fp1, Fp2, F3, F4, FT9, FT10, C3', C4', P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, P9, P10, PO9, PO10, left (A1) and right (A2) mastoid. The recording positions are illustrated in Appendix A. The A1 electrode served as initial common reference and a forehead electrode (AFz) served as ground. Electrode positions conformed the modified international 10-20-System [Pivik, 93]. Electrode impedances were kept below 10 kΩ and were typically below 5 kΩ. The horizontal electro-oculogram (EOG) was recorded from the outer canthi of both eyes, and the vertical EOG was monitored from an electrode below the left eye against Fp1. The

EEG was continuously digitized with a sampling rate of 250 Hz. All signals were recorded with low-pass filters set to 30 Hz. Offline epochs were generated starting from 200 ms before stimulus onset until 1800 ms after stimulus onset. A second order Butterworth filter simulation with a 0.01 Hz high-pass filter was performed with zero-phase shift on data. EEG activity was aligned to a 200 ms pre-stimulus baseline. All trials were visually inspected for artefacts of ocular (e.g. blinks, saccades) and non-ocular origin (e.g. channel blockings or drifts). Trials with non-ocular artefacts and trials with incorrect behavioural responses had been discarded. For all other trials, ocular contributions to the EEG were corrected [Berg, 86]. ERPs were then averaged separately for each channel and for each experimental condition. Each averaged ERP was low-pass filtered at 10 Hz with a zero phase shift filter, and recalculated to average reference. The average reference is free from asymptotic appropriate reference site and distinguishes topographical differences by eliminating the activity shared by all electrodes [Lehmann, 92]. At least 20 trials per average were involved.

2.1.2.6 Statistical Analyses

The aim of the data analysis is to define and extract behavioural data and ERP components due to repetition priming of faces and to determine whether the ERP effects of repetition priming are dissociable, on one hand, for familiar and unfamiliar faces because of the mask and, on the other hand, during the course of ERPs towards the target face. Behavioural data comprised mean RTs and mean PEs as reflecting the mean error rate of unfamiliar stimuli incorrectly rated as familiar and familiar stimuli rated as unfamiliar. The terms mean error rate and percentages of error will be use synonymously in the present thesis. Behavioural data, peak latencies (baseline-to-peak) and peak amplitudes as well as mean amplitudes and ERP distributions (topographies) are diagrammed (polarity: positive values upward) and were evaluated using conservative F-tests [Huynh, 76]. The Huynh-Feldt correction was applied to all ANOVAS. A α-level of .05 was used for all statistical analyses and Bonferroni corrected when post-hoc analyses (pair wise comparisons) were performed [Bortz, 93]. This will be indicated during the appropriate text passages and tables. The results are provided by uncorrected degrees of freedom, the corrected *p*-Value. Analyses of variance (ANOVAs) with repeated measures including the within-subject variables familiarity with two levels (familiar vs. unfamiliar) and repetition priming with three levels (primed vs. unprimed congruent or incongruent, see 2.1.2.3) were performed.

ANOVAs for ERPs included the additional repeated measurement factor electrode (28 levels) and were conducted with average referenced data (eye electrodes omitted). Thus, condition effects in these ANOVAs are only meaningful in interaction with electrode. Therefore all later reported effects include the factor electrode, which will not be mentioned anymore with regard to brevity.

ERPs were quantified with mean amplitude measures in the time segments 80-130 ms, 150-220 ms, 220-260, 260-300, 300-340, 340-380, 380-420, 420-460, 460-500, 500-540, 540-580, 580-620, 620-660 and 660-700 ms. The first two segments were chosen to correspond to P100 and N170, the following 40 ms segments were chosen in order to evaluate the ERE and LRE. For pair wise comparisons of primed and unprimed conditions, effect sizes are provided in terms of explained variance (partial eta square - η_p^2) per time segment [Cohen, 88]. ANOVAs of peak latencies and peak amplitudes were then performed for P100, N170 and the ERE analogous to those for the RT data. For the time segments corresponding to the P100, N170 and to the ERE hemispheric asymmetries were tested by dropping the midline electrodes and categorizing the others as belonging to the left and right scalp on a new factor: hemisphere. Thus, ANOVAS had been performed with the variables repetition, familiarity and hemisphere.
As a main point in data analyses topographies of the difference waveforms (primed minus unprimed faces in the familiar and unfamiliar conditions) showing the ERE and the LRE were qualitatively determined whether they differed over time segments or between conditions. Dissociable topographies may derive from differences in the underlying neuronal source configuration. Still topographic differences can be interpreted in that way only when differences in source strength are ruled out. For that reason so called profile analysis [McCarthy, 85] were conducted. Amplitude differences in the corresponding time segments were removed by vector scaling, a strategy described by McCarthy and Wood [McCarthy, 85] and recommended by Picton et al. [Picton, 00]. This technique eliminates overall amplitude differences between distributions while preserving the topographic shapes. Accepting that the distribution for each condition is represented as a vector in N-space its axes are the voltages at each of the electrode locations. Amplitude strength is given by the length of its vector, whereas its shape depends on the vector's orientation. Vector length is defined by the square root of the sum of squared voltages over all electrodes. The vector length was computed of the grand mean distribution across

participants for a given condition. Each participant's condition mean was divided by this factor. Thus, amplitude differences between conditions are eliminated by scaling the voltages by its corresponding vector length. After the data had been scaled ANOVAs as described above were used to assess the significance of topographic profile interactions with time segments or experimental condition. To separate repetition priming effects over time, ANOVAs included an additional factor time with two levels. Electrode by condition interactions that are still significant on these scaled distributions indicate different scalp topographies. One may conclude that these differences originate from at least some different spatial configurations of the generators. This would justify inferences for distinguishable cognitive processes, for example concerning the ERE indicating FRU activation.

Urbach and Kutas [Urbach, 02] criticized the application of vector scaling. Vector scaling might lead to invalid inferences to differences in source configurations for the following reasons: It has to be defined exactly what is meant by generator, respectively its configuration and strength. If multiple sources are assumed to be part of a process simultaneously the corresponding strengths and spatial configuration might be confounded. Concerning ERE investigation dipole source modelling for example by Schweinberger et al. [Schweinberger, 02b] suggested that the ERE may originate mainly from the fusiform gyrus. This was indicated by dipole pairs in inferior temporal brain areas. Based on these results it is supposed that there is one neural source that mainly generates the ERE. Remaining baseline differences between conditions and electrodes can result in differences in the topographic shape even if the post-stimulus generators do not differ. In the present study data analysis was performed on average referenced data so that biases caused by a single reference site should be eliminated. Thus, overall baseline differences are not a strong concern. Another issue is noise variability in ERP measurements, because it contributes to the amplitude of a distribution and tends to increase vector length. This might lead to noise-intended overcorrection and can result in residual differences in topographic shape. The mean number of error and artefact free trials that contributed to an individual averaged ERP was M = 25.50 (SD = 3.09). Thus small effects have to be interpreted with caution and must not be overrated. Vector scaling is based on the mean values on all electrode locations across all participants, which minimises the effect of noise. Still, when scaling is used to determine differences in scalp distributions using

vector scaling as described by McCarthy & Wood [McCarthy, 85] the issues pointed out by Urbach and Kutas [Urbach, 02] should be kept in mind.

2.1.3 Results

2.1.3.1 Behavioural Data

RTs and PEs to target faces are summarized in *Table 3* and *Figure 6*. An inspection of this data shows that not all error rates varied with priming conditions in a similar way as with RTs. Namely error rates in the unprimed congruent conditions were lower compared to the primed conditions.

2.1.3.1.1 Reaction times (RTs)

RTs to familiar target faces were generally faster, M = 683.13 ms (SD = 13.76), compared to unfamiliar faces, M = 766.23 ms (SD = 23.09). This is reflected by a significant effect of familiarity, F (1, 15) = 30.88, $p < .001$. Moreover repetition priming affected familiar and unfamiliar faces, thus a significant effect of repetition priming was found, F (1, 15) = 136.44, $p < .001$. Repetition priming was affected by familiarity of the target shown by a significant interaction of familiarity by repetition priming, F(2, 30) = 49.25, $p < .001$, reflecting that on average RTs to primed familiar targets were 179 ms faster than RTs to their unprimed presentations and 71 ms faster to repeated unfamiliar targets compared to unprimed unfamiliar targets. Thus, the repetition effect was significantly larger for familiar than for unfamiliar faces, F (1, 15) = 74.58, $p < .001$. For further contrasts significance level was Bonferroni corrected to p = .01. For familiar target faces there was a significant overall effect of repetition priming, F (2, 30) = 270.16, p < .001, which was somewhat larger when the incongruent unprimed condition (FUU) was contrasted with the primed condition, F (1, 15) = 447.90, p < .001. When a familiar target was preceded by a different familiar face (congruent unprimed condition) the effect was still significant but smaller, F (1, 15) = 256.95, p < .001. It seems that the congruence of prime-target-combination interferes with priming. Still, a comparison of these two repetition priming effects vanished into a trend after Bonferroni correction, F (1, 15) = 4.87, p < .10. For unfamiliar targets there was also a clear effect of repetition priming, F (2, 30) = 24.62, p < .001, which was larger for the incongruent condition, F (1, 15) = 33.62, p < .001, as for the congruent condition, F (1, 15) = 18.50, p < .001. Here, the difference between the repetition priming effects reached significance, F (1, 15) = 11.89, p < .01.

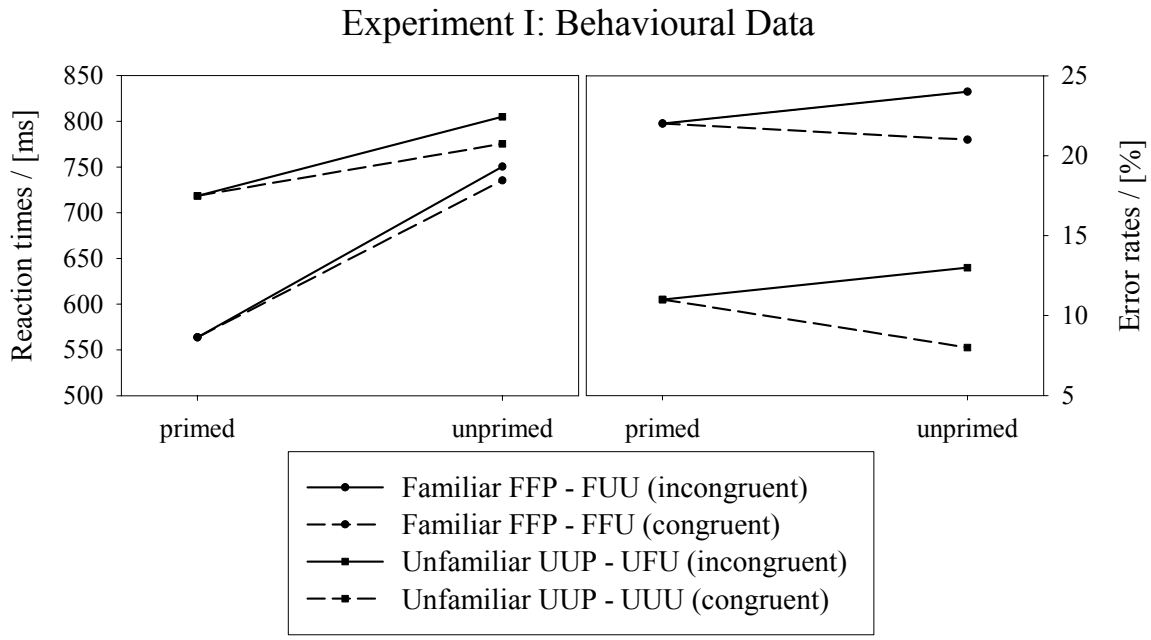


Figure 6: *Experiment I: Left: RTs and Right: PEs in Experiment I*

Table 3: *Experiment I: Mean RTs and PEs in Experiment I*

Type of target and prime	**Mean RT (SD) ms**	**PE (SD)**
Familiar target		
Identical prime (FFP)	563 (66)	22 (12)
Unprimed congruent (FFU))	735 (52)	21 (8)
Unprimed incongruent (FUU)	750 (56)	24 (9)
Priming effect congruent (FFP-FFU)	172	-1
Priming effect incongruent (FFP-FUU)	187	2
Unfamiliar target		
Identical prime (UUP)	718 (112)	11 (12)
Unprimed congruent (UUU))	775 (92)	8 (10)
Unprimed incongruent (UFU)	804 (83)	13 (12)
Priming effect congruent (UUP-UUU)	57	-2
Priming effect incongruent (UUP-UFU)	86	2

FFP = familiar familiar primed; FFU = familiar familiar unprimed (con.); FUU = familiar unfamiliar unprimed (incon.); UUP = unfamiliar unfamiliar primed; UUU = unfamiliar unfamiliar unprimed (con.); UFU = unfamiliar familiar unprimed (incon.)

2.1.3.1.2 Percentage of errors (PEs)

Participants judged familiar people as being unfamiliar more frequently than unfamiliar targets as familiar. PEs for familiar faces ranged from 21% to 24 % and to unfamiliar faces from 8% to 13%. There was an effect of familiarity, F (2, 30) = 8.40, $p < .05$, and repetition priming, F (2, 30) = 4.43, $p < .05$ and no interaction of familiarity and repetition priming. Highest PEs emerged in incongruent unprimed conditions for familiar and unfamiliar targets. Lowest PEs appeared for congruent unprimed conditions. The difference between congruent and incongruent unprimed conditions reached significance for unfamiliar targets, F (1, 15) = 11.13, $p < .01$. Pair wise comparisons for familiar targets between primed and congruent and incongruent unprimed conditions and unfamiliar targets between the primed and the unprimed incongruent condition failed to reach significance, Fs < 3.30. Repetition priming of unfamiliar targets caused significantly shorter RTs, but higher PEs when contrasted to the unprimed congruent condition. A speed-accuracy trade off could not be validated. Pair wise comparison of PEs for the primed and unprimed congruent condition yielded only a trend when Bonferroni corrected, Fs (1, 15) < 5.87, $p < .10$.

2.1.3.2 Event related Potentials (ERPs)

For ERPs of familiar and unfamiliar target faces, see *Figures 7* and *8* respectively. The Figures contain ERPs and primed or unprimed faces from -200 to 800 ms diagrammed by different lines. For reasons of facility of inspection, all electrodes are displayed beside F7/F8 and P7/P8.These electrodes were chosen to be omitted because the ERPs resemble the ERP on A1/A2 and P9/P10, where the ERE was prominent in this experiment. An effect of familiarity was seen from 220 ms onwards. Effects of repetition priming and interaction of repetition by familiarity started at 260 ms and lasted until 620 ms, by which time reactions had been executed. Detailed descriptions of ERPs follow this section. Effects are highlighted by calculating difference waves between the second and the first presentation (primed minus unprimed), shown in *Figure 9* for familiar and unfamiliar faces together at electrode sites Fz, Pz, A1/A2, P9/P10.

2.1.3.2.1 P100

P100 for target faces was quantified with mean amplitude measures in the time segment 80 to 130 ms. Analysis of mean amplitude in this time segment yielded no effects. In addition ANOVAs of peak latency and peak amplitude, as time of maximum voltage in the segment

80-130 ms were performed at O1 and O2 electrode, where P100 was most pronounced (*Table 4*).

Table 4: *Experiment I: Mean peak latency (L in ms) and amplitude (A in μV) for P100*

	P100			
Condition	O1		O2	
	L (SD)	A(SD)	L(SD)	A(SD)
FFP	113 (24)	1.5 (2.6)	110 (26)	2.2 (3.4)
FFU	104 (28)	1.6 (2.8)	107 (26)	2.0 (3.2)
FUU	105 (24)	1.6 (2.8)	112 (25)	2.0 (3.3)
UUP	112 (18)	1.8 (2.8)	114 (22)	2.4 (3.3)
UUU	105 (23)	1.9 (3.1)	111 (24)	2.3 (3.3)
UFU	106 (25)	1.8 (2.7)	108 (26)	2.3 (3.2)

FFP = familiar familiar primed; FFU = familiar familiar unprimed (con.); FUU = familiar unfamiliar unprimed (incon.); UUP = unfamiliar unfamiliar primed; UUU = unfamiliar unfamiliar unprimed (con.); UFU = unfamiliar familiar unprimed (incon.)

The mean peak latency of the P100 was M = 108.91 ms (SD = 3.50). There were slight differences in latencies and peak amplitudes between primed and unprimed, familiar and unfamiliar target faces. Although the P100 peaked somewhat earlier in unprimed conditions (5 to 9 ms), this difference failed to reach significance at both electrode sites, $F < 1$. In addition no significant effect of familiarity or interaction familiarity by repetition primi was observed. As indicated by *Table 4* the P100 is more pronounced in the right hemisphere. Peak am-plitudes at O1, M = 1.70 μV (SD = 0.17), were smaller compared to O2, M = 2.20 μV (SD = 0.14). The difference between the left and the right hemisphere was assessed by perfor-ming ANOVAs on the mean amplitude measures in time segment 80 to 130 ms, dropping the midline electrodes and including a factor hemisphere. This analysis revealed a main effect of hemisphere, F (11, 165) = 4.05, $p < .01$, and an interaction of hemisphere by repe-tition priming, F (22, 330) = 1.98, $p < .01$. The effect of hemisphere was strongest in primed conditions, F (11, 165) = 5.16, $p < .01$, compared to unprimed conditions, F (11, 165) = 4.38, $p < .01$. This is not particularly reflected by peak amplitudes at O1/O2. Here the effect of hemisphere, F (11, 165) = 3.30, $p < .05$, and the interaction of hemisphere by repetition priming, F (22, 330) = 2.09, $p < .05$, is

characterized by a stronger right hemis-pheric asymmetry for primed targets, F (11, 165) = 7.53, $p < .01$, compared to unprimed targets, F (11, 165) = 6.48, $p < .01$.

2.1.3.2.2 N170

N170 amplitude was measured as mean amplitude between 150 and 220 ms and showed no effects of familiarity, repetition priming or an interaction of both. In this time segment N170 peak latency and amplitude was measured as minimum at PO9 and PO10 electrode, where the peak was most pronounced (*Table 5*). At PO9, amplitudes for familiar faces were somewhat larger, M = -2.16 µV (SD = .05), compared to peak-amplitudes for unfamiliar faces, M = -1.76 µV (SD = .40), which did not reach significance. Also slight shifts in latency (6 to 10 ms) did not reach significance, M = 175.66 ms (SD = 4.84). At PO10 neither differences in latency, M = 180.66 ms (SD = 5.60), nor in peak amplitudes per condition were observed, M = 2.06 µV (SD = .24). Analyses of hemispheric differences in time segment 150 to 220 ms yielded no main effect hemisphere, F (11, 165) = 1.65.

Table 5: *Experiment I: Mean peak latency (L in ms) and amplitude (A in µV) for N170*

	N170			
Condition	PO9		PO10	
	L (SD)	A (SD)	L (SD)	A (SD)
FFP	182 (29)	-2,2 (3,5)	174 (26)	-1,9 (4,6)
FFU	178 (31)	-2,2 (3,5)	164 (34)	-2,1 (4,2)
FUU	179 (32)	-2,1 (3,6)	170 (33)	-2,0 (4,5)
UUP	174 (22)	-2,0 (3,4)	178 (22)	-1,8 (4,4)
UUU	172 (29)	-1,3 (3,4)	174 (28)	-2,5 (4,4)
UFU	169 (32)	-2,0 (3,1)	176 (27)	-2,1 (4,2)

FFP = familiar familiar primed; FFU = familiar familiar unprimed (con.); FUU = familiar unfamiliar unprimed (incon.); UUP = unfamiliar unfamiliar primed; UUU = unfamiliar unfamiliar unprimed (con.); UFU = unfamiliar familiar unprimed (incon.)

The interaction of hemisphere by familiarity reached significance, F (11, 165) = 5.12, $p <$ .001, which was due to stronger right hemispheric preponderance for unfamiliar targets com-pared to familiar targets. Post-hoc comparisons per familiarity yielded no significant results, Fs < 1.

2.1.3.2.3 Repetition priming effects

To analyse repetition effects to target faces mean amplitude measures were quantified in 12 adjacent 40 ms time segments from 220 to 700 ms. *Table 6* contains the Bonferroni-corrected results of ANOVAs that had been performed per time segment. For repetition priming effects effect sizes are specified. In *Figures 7* and *8* ERPs to primed and unprimed targets are displayed. Difference waves in *Figure 9* provide a direct comparison of the repetition priming effects in the congruent and incongruent conditions for familiar and unfamiliar targets. Overall ANOVA revealed a main effect of repetition priming that started in segment 300-340 ms, was strongest from 460-500 ms and disappeared after 620 ms. When compared to familiar target faces, ERPs to unfamiliar target faces were affected by repetition priming about 120 ms later. ERP modulations appeared much smaller for unfamiliar faces. This is indicated by the overall ANOVA which revealed a significant interaction of familiarity and repetition starting at 260-300 ms lasting until the end of the recording epoch. Repetition priming of familiar targets elicited an increased positivity or decreased negativity at the vertex, whereas at prefrontal sites the polarity reversed. These effects were maximal around 400-500 ms but lasted until the end of the recording epoch. Repetition priming also affected an earlier transient component that corresponds to the ERE (*Figure 9*). Here a temporally limited modulation appeared around 260 ms peaked at 300 ms and disappeared around 380 ms. The component is particularly visible at the Fz electrode and reversed polarity towards the temporo-occipital sites, most evident at A1/A2 but also detectable at P9/P10. Around 380 ms the ERE passes into the later component of the repetition priming effect. The LRE is characterised by a central and parieto-central positivity for primed targets and reverses polarity at prefrontal electrode sites. It reaches a maximum in time segment 460-500 ms and lasts until 620 ms. Overall ANOVA revealed an effect of familiarity which began in the 220-260 ms segment, lasted until the end of the recording epoch and reached its maximum in segment 460-500 ms.

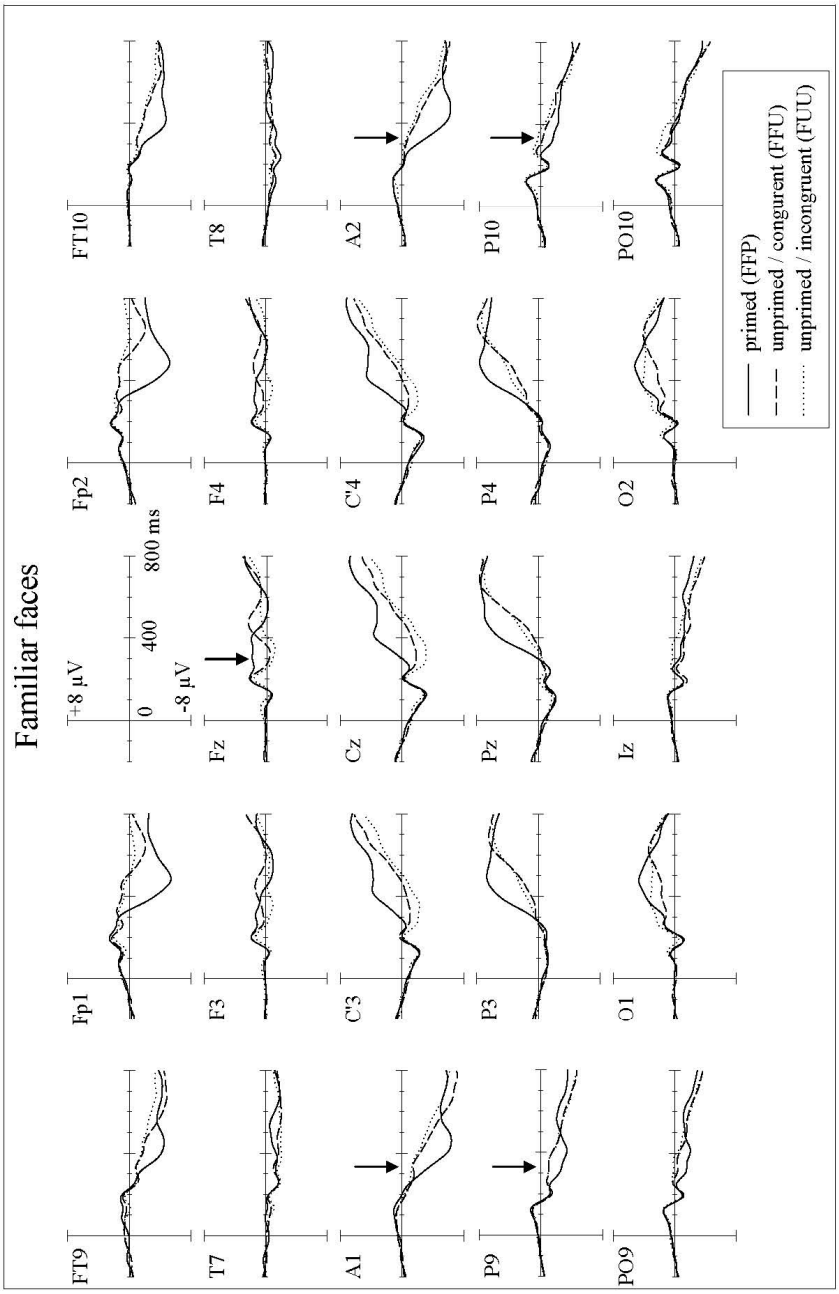


Figure 7: *Experiment I: ERPs to familiar targets (primed versus unprimed)*

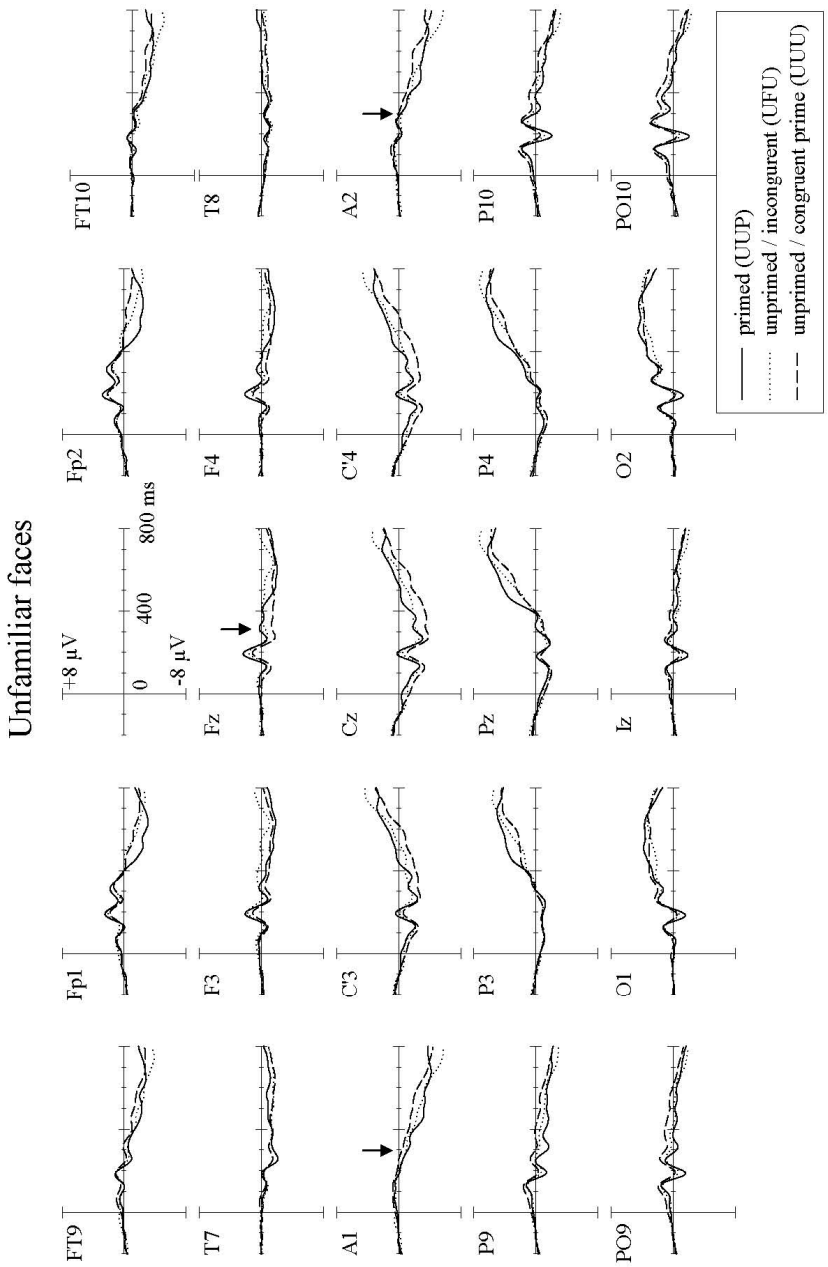


Figure 8: *Experiment I: ERPs for unfamiliar targets (primed vs. unprimed)*

Table 6: *Experiment I: Results of thge ANOVAS for amplitude measures of the repetition ERP components*

		Time segment (ms)											
Source	df	80-130	150-220	220-260	260-300	300-340	340-380	380-420	420-460	460-500	500-540	540-580	580-620	620-660	660-700
All conditions:															
Familiarity	27, 405			6.74***	6.59***	4.27**	8.86***	11.88***	13.56***	14.58***	11.61***	9.98***	10.82***	10.24***	8.69***
Repetition	54, 810					3.46*	5.86***	9.80***	14.42***	16.30***	10.10***	5.10**	2.71*		
Familiarity x Repetition	54, 810		1.75(*)	1.84(*)	2.49*	4.02**	7.57***	9.37***	8.16***	6.39***	3.55**	2.31*	1.89(*)	2.21*	2.78**
Familiar															
Repetition	54, 810				2.35(*)	5.34***	10.03***	13.10***	14.80***	15.70***	9.41***	4.32**	2.19(*)	2.02(*)	2.64*
FFP - FFU	27, 405					5.01**	11.34***	16.59***	20.94***	23.42***	11.17***	4.12*			
η_p^2						.25	.43	.52	.58	.61	.42	.21			
FFP - FUU	27, 405				3.46(*)	7.21***	12.29***	14.45***	16.17***	17.86***	12.49***	6.33**	3.11(*)		3.23(*)
η_p^2						.33	.45	.49	.52	.54	.45	.29			
Unfamiliar															
Repetition	54, 810							2.32(*)	3.92***	4.52***	3.26**	3.03**	2.64*		
UUP - UUU	27, 405								5.04**	5.92***	4.19**	4.17**	4.15**		
η_p^2									.25	.28	.22	.22	.22		
UUP - UFU	27, 405								2.72*	4.48**	2.83(*)				
η_p^2									.15	.23					

(*)p < .10 (Trend); *p < .05; **p < .01 ; ***p < .001 Bonferroni-corrected α - level for pairwise comparisons; not significant (n.s.) F-values not listed; η_p^2 = explained variance (effect size); FFP = familiar (target) familiar (prime) primed; FFU = familiar familiar unprimed; FUU = familiar unfamiliar unprimed; UUP = unfamiliar unfamiliar primed; UUU = unfamiliar unfamiliar unprimed; UFU = unfamiliar familiar unprimed

2.1.3.2.3.1 Early repetition effect (ERE)

As described in the foregoing section the ERE starts at 260 ms and disappeares around 380 ms (*Figure 9*). Pair wise comparisons between primed and unprimed conditions were performed (*Table 6*). They revealed a repetition priming effect for familiar faces (unprimed incongruent condition) that started in time segment 260-300 ms as a trend and reached significance in the consecutive time segment. In the unprimed congruent condition, the ERE only reached significance in the time segment 300-340 ms. When the unprimed congruent and unprimed incongruent conditions were compared, a slight difference was found as a trend in time segment, 300-340 ms, F (27, 405) = 2.69, $p < .10$, reflecting that the ERE is somewhat larger in reference to the unprimed incongruent condition. According to that the effect size (explained variance) for the ERE in the unprimed incongruent condition (33%) is somewhat larger compared to the ERE in the unprimed congruent (25%) condition. Still, the difference is small and does not show a consistent picture over all electrodes. It is well visible at fronto-central electrodes. Repetition of unfamiliar targets caused a weak positivity for primed faces around 300 ms at fronto-cental electrodes as well. Comparable to familiar faces the effect changed polarity towards inferior temporal sites. Still, a priming effect from 260-300 and 300-340 ms did not reach significance, Fs (27, 405) = 1.65 and 2.06.

Hemispheric differences in repetition priming effects:

The early modulation of the repetition effect, as described above, with its maximum around 300 ms appeared to be larger over the right hemisphere (*Table 7)* at peak amplitude A2, (M = 2.89 µV; SD = .71), compared to A1, (M = 2.43 µV; SD = .65). As before asymmetries were analysed. This analysis yielded only for familiar faces a significant effect of hemisphere in time segment 260-300 ms, F (11, 165) = 3.96, $p < .05$, and persisted as a trend until time segment 420 ms, Fs (11, 165) < 3.14, ps < .10, and disappeared thereafter, Fs < 1. For unfamiliar target faces no hemispheric asymmetries could be found.

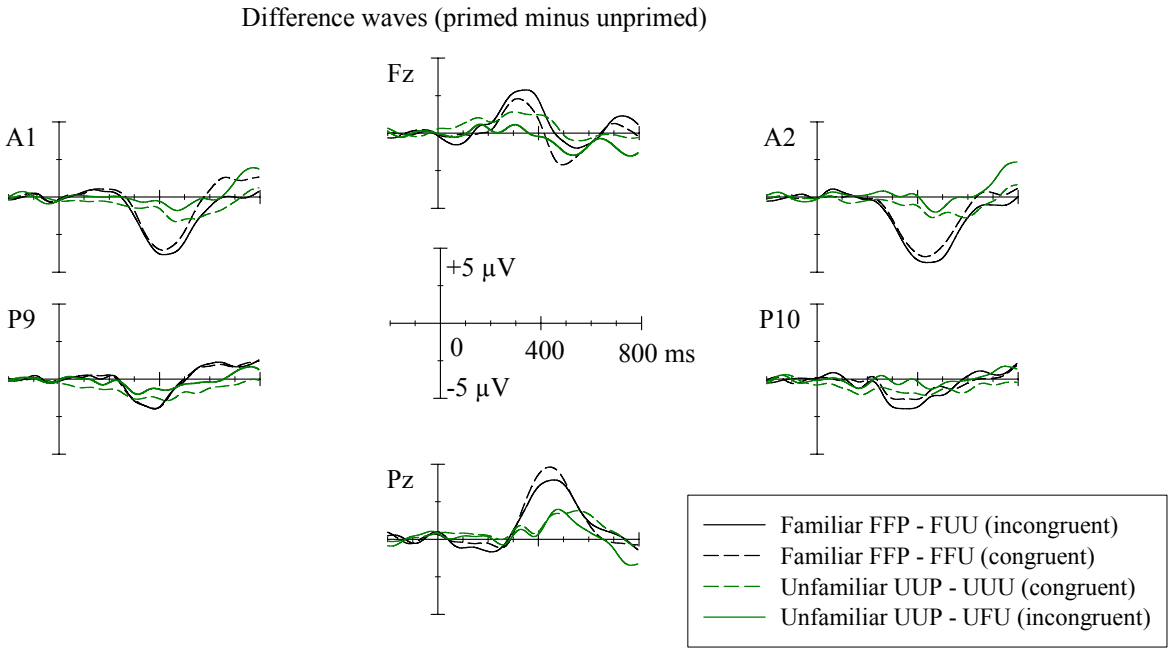


Figure 9: *Difference waves for familiar and unfamiliar targets*

Table 7: *Experiment I: Mean peak latency (in ms) and amplitude (in µV) for the ERE*

	ERE					
	Fz		A1		A2	
	L(SD)	A(SD)	L(SD)	A(SD)	L(SD)	A(SD)
FFP-FFU	309 (28)	3.2 (3.4)	335 (12)	-2.3 (2.6)	332 (20)	-2.8 (2.9)
FFP-FUU	323 (23)	3.6 (2.7)	333 (17)	-2.5 (2.9)	331 (19)	-3.0 (3.1)
UUP-UUU	301 (31)	2.2 (3.2)	307 (32)	-1.2 (2.1)	307 (32)	-1.0 (1.5)
UUP-UFU	307 (28)	1.1 (3.1)	303 (32)	- 0.8(2.3)	311 (29)	-0.3 (1.8)

FFP = familiar familiar primed; FFU = familiar familiar unprimed (con.); FUU = familiar unfamiliar unprimed (incon.); UUP = unfamiliar unfamiliar primed; UUU = unfamiliar unfamiliar unprimed (con.); UFU = unfamiliar familiar unprimed (incon.)

ERE – Peaks and Latencies:

In the time segment 260-340 ms peak latency and amplitude was measured as a minimum at A1/A2, P9/P10 and a maximum at Fz electrode, where the peak was most pronounced. Results are compiled in *Table 7.* The difference waves (*Figure 9*) show the ERE to be much smaller for unfamiliar target faces. Inspection of the 300-340 ms suggests that there is a beginning overlap with the late component of repetition priming, with central positivity and prefrontal negativity which reaches maximum at 460-500 ms, visible at Pz. Still, the

time segment 300-340 ms corresponds to the ERE because of its peak, particularly visible at Fz, and its specificity to familiarity. At Fz peak latency of the ERE is somewhat delayed (14 ms) for familiar targets in the incongruent condition (FFP-FUU) compared to the congruent condition (FFP–FFU) which did not reach significance, F (1, 15) = 4.50. Differences in peak amplitudes for familiar targets seem to be somewhat larger (0.4 μV) in the incongruent condition (FFP-FUU) compared to the congruent condition (FFP–FFU), which did not reach significance either, Fs < 1. Thus, an ERE for familiar target faces was found ranging from, M = 3.40 μV (SD = 0.28) at Fz to M = - 2.90 μV (SD = 0.14) at A2.

2.1.3.2.3.2 Late repetition effect (LRE)

The LRE can be seen best at Pz by calculating difference waves between the second and the first presentation for unfamiliar and familiar faces shown in *Figure 9* and in *Figures 7* and *8*, where the prefrontal negativity is well visible at Fp1/Fp2. As well as the inspection of the ERPs and difference waves that reveals the beginning of the LRE around 380 ms there are two results that seem to indicate the beginning of the LRE. First, pair wise comparisons revealed a priming effect for unfamiliar faces that started in time segment 380-420 ms as a trend. The repetition priming effect was strongest from 460-500 ms and lasted until 580-620 ms. Thus, repetition priming affected ERPs towards unfamiliar faces 120 ms later and was much smaller in amplitude compared to those for familiar faces. Accordingly for unfamiliar faces the effect sizes (explained variances), 28% for the unprimed congruent and 23% for the unprimed incongruent condition in time segment 460-500ms, were much weaker than the LRE for familiar faces, 61% for the unprimed congruent and 54% for the unprimed incongruent condition. This is reflected by the familiarity effect in this time segment. Second, the LRE for familiar target faces with a maximum at 460-500 ms was strongest in the congruent unprimed condition from 380 ms onwards. This was confirmed by separate ANOVAs to test differences between the congruent and incongruent unprimed conditions.

Familiar targets: While the repetition priming effect in time segment 340-380 ms appeared to be stronger in the incongruent than the congruent unprimed condition, F (27, 405) = 3.87, p < .05, after 380 ms the difference reversed. This difference reached significance from 380-420 ms, (F (27, 405) = 3.41, p < .05. *Unfamiliar targets*: Again, the repetition priming effect appeared to be stronger in the congruent unprimed condition. This

difference reached significance from 420 to 500 ms, *F*s (27, 405) = 4.00 and 2.65, *p*s < .01 and .05. Note that the difference according to prime-target congruence is small and particularly well visible at parieto-central and occipital electrodes.

2.1.3.2.3.3 Topographic analysis

Difference waves (*Figure 9*) and topographic maps (*Figure 10*) suggest at least two qualitatively different priming effects between 300 and 580 ms. Specifically priming between 300 and 380 ms caused increased negativity at inferior temporal electrodes and increased positivity at midfrontal electrodes (ERE). In contrast, between 380 to 580 ms priming caused increased positivity at parietal and central electrodes and increased negativity at prefrontal sites (LRE).

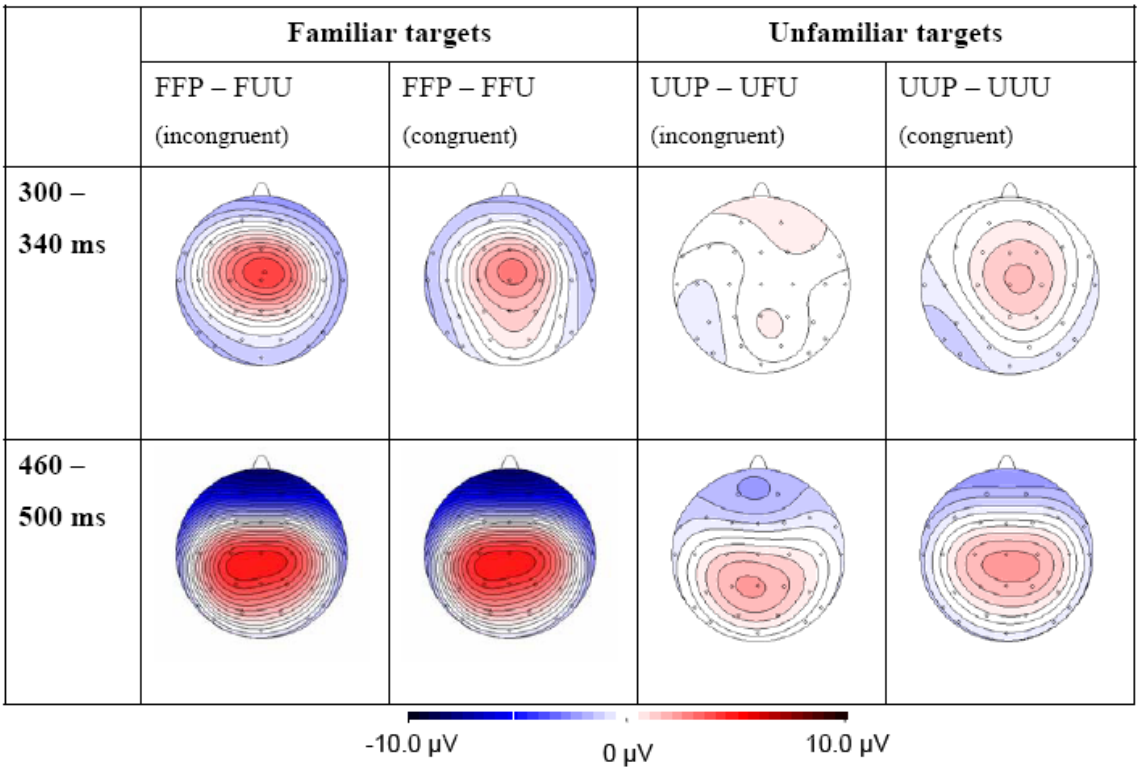


Figure 10: Experiment I: Voltage maps of ERP difference waves between primed and unprimed conditions showing ERE in time segment 300-340 ms and LRE in time segment 460-500 ms. Spherical spline interpolation was used. Equipotential lines are separated by 0.50 µV.

To determine whether these effects of repetition priming in the 300 to 380 ms segments were topographically dissociable from those seen in the 380 to 580 segments differences (primed minus unprimed congruent or incongruent) of mean amplitudes for familiar and unfamiliar targets were used and were scaled for the consecutive time segments from 300 to 580 ms (see 2.1.2.6). For familiar targets ANOVAs of the primed minus unprimed incongruent difference compared the scaled amplitudes for the time segments from 300-340, 340-380, 380-420, 420-460, 460-500, 500-540 and 540-580 ms were compared. It turned out that the difference changed qualitatively from 300-420 to 420-460 ms, *F*s (27, 405) > 3.90, *p*s < .05. From 300-420 ms consecutive time segments were topographically indistinguishable as well as time segments from 420-580 ms, *F*s < 1. ANOVAs of the primed minus unprimed congruent difference revealed a similar result. Here the segment 300-340 ms was different from segments 460 to 540 ms, *F*s (27, 405) > 3.56, *p*s < .05. For consecutive time segments 300 to 420 ms as well as from 460 to 580 ms no differences had been found, *F*s < 1. ANOVAs of the primed minus unprimed congruent difference waves for unfamiliar faces revealed a difference from 420-460 ms to 460-500 ms, F (27, 405) = 4.01, p < .05. There was no significant difference in the primed minus unprimed incongruent condition. In *Figure 10* the topographies for the ERE in time segment 300-340 ms and for LRE in time segment 460-500 ms are displayed, because pair wise comparisons of primed and unprimed conditions with the unscaled amplitudes reached highest effect size (η_p^2) in this time segment (*Table 6*) and pair wise comparisons between these time segments reached highest F-values for the congruent and the incongruent condition, *F*s (27, 405) = 4.74 and 3.63, *p*s < .01 and.05.

In a second set of analysis it was determined whether the repetition priming effects showed a familiarity specific topography. The ERE in time segment 300-340 ms was confined to familiar faces, and thus, familiarity specific. The LRE was statistically significant for both familiar and unfamiliar faces and from time segment 380-420 ms onwards and lasted until 620 ms. Pair wise comparisons of the time segments where the LRE was significant revealed no significant differences between familiar and unfamiliar faces. Thus, from 380 ms onwards the topography of the LRE was not affected by familiarity, *Fs* < 1.

A third part of analyses was done to compare topographies regarding congruence of the prime-target combination in the unprimed condition. For familiar faces this was especially done for the time segment from 300-340 ms where the ERE was determined. Here

ANOVA yielded only a trend, F (27, 405) = 2.02, $p < .10$. As the unscaled data revealed a difference in the next segment 340-380ms a corresponding difference was found in topographies, F (27, 405) = 3.67, $p < .05$, as well as for the following segment 380-420 ms, F (27, 405) = 3.43, $p < .05$, but not thereafter. For unfamiliar targets in two time segments from 420 to 500 ms topographies turned out to be qualitatively different, Fs (27, 405) > 2.60, ps < .05. This was not surprising because the unscaled data had already revealed a difference from 420-460ms. Taken together the congruence concerning familiarity of prime and target in the unprimed conditions influences the beginning of the LRE, leaving the preceding ERE unaffected.

2.1.4 Discussion

Experiment I was designed to extract repetition priming that is based on facial representation in LTM and to impede repetition priming due to STM and based on perceptual processes. A repetition priming paradigm with a face mask backwards to the prime stimulus was applied and combined with a familiarity decision task as an implicit memory test.

2.1.4.1 Behavioural Data

In RTs priming for both familiar and unfamiliar faces was found to be highly reliable which confirms the hypothesis 1 as outlined in 2.1.1 and replicates former results e.g. [Bruce, 85] [Burton, 98] [Ellis, 87] [Pfütze, 02] [Schweinberger, 95]. RTs on both familiar and unfamiliar primed targets were shorter compared to the unprimed condition. Additionally the repetition priming effect interacted with familiarity in that benefits being larger from priming for familiar than unfamiliar faces. Thus Experiment I replicates previous findings concerning experiments where prime and target were presented immediately [Ellis, 90] [Herzmann, 04] [Schweinberger, 95] and concerning experiments where faces [Boehm, 06b] [Pfütze, 02] or pattern masks interspersed between the prime and the target [Engst, 06]. In reference to FRU activation immediate repetition priming of familiar faces causes facilitation of perceptual and representation based processes. Immediate repetition priming effects for unfamiliar faces can be interpreted as reflecting perceptual short-term activation [Schweinberger, 95]. Using a repetition priming paradigm with backward masking repetition priming for unfamiliar faces cannot be explained by perceptual-based priming, as the unfamiliar face that interspersed prime and target should have interrupted short-term activation and was to impede the continuous transfer of

structural encoding to the FRU formation of formerly unknown faces as simulated by [Burton, 94]. Still, not very much is known about the beginning of the formation of internal facial representations and of FRUs respectively (see 1.3.3). At the level of individual neurons in the monkey brain Rolls, Baylis, Hasselmo and Nalwa [Rolls, 89] found strongest alterations of face-selective neural response after the first two repetitions. Salasso, Shiffrin & Feustel [Salasso, 85] investigated repetition effects on words and pseudo-words and tried to trace the development of memory codes of repeated pseudo-words. After approximately five repetitions words and pseudo-words were identified equally accurately, suggesting that codification had been completed for pseudo-words. Assuming transferability of these results to human face recognition processes, repetition enhancement for unfamiliar faces after the first repetition might not be attributed to the gradual formation of new perceptual representations. Repetition priming of unfamiliar faces by means of faster decision making might be rather based on accelerated short-term activation of visually derived semantic information. This might be information about gender or age relying more on external more changeable aspects of a face rather than internal configuration e.g. [Ellis, 75] [Hancock, 00] [Young, 85b]. The discussion of electrophysiological correlates in 2.1.4.2 will shed more light onto this debate. Stimulus presentation times and SOAs in Experiment I were chosen to gain comparable results to the experiments by Schweinberger et al. [Schweinberger, 95] and Pfütze et al. [Pfütze, 02]. On a descriptive level, RTs show the same pattern apart from the fact that repetition priming caused less facilitation to both familiar and unfamiliar target faces and higher reaction times in general compared to Schweinberger et al. [Schweinberger, 95]. In the unprimed incongruent condition the repetition priming effect for familiar faces in Experiment I was 21 ms smaller than that found by Schweinberger et al. [Schweinberger, 95].

With respect to the congruence between familiarity of the prime and familiarity of the target Experiment I provided a direct comparison between two different unprimed conditions. In the incongruent condition an unfamiliar prime preceded the familiar target or a familiar prime preceded the unfamiliar target. In the congruent unprimed condition both prime and target are either familiar or unfamiliar. The repetition priming effect resulting from the difference of primed and unprimed incongruent condition is somewhat larger compared to the priming effect resulting from primed minus unprimed congruent condition

for familiar as well as for unfamiliar targets, although, significant only for unfamiliar targets. Descriptively, for unfamiliar faces Schweinberger et al. ([Schweinberger, 95] Experiment 1, Table 1, p. 725) found the same result, showing a larger repetition priming effect in the unprimed incongruent condition (RT familiar prime > RT unfamiliar prime). For familiar faces Schweinberger et al. ([Schweinberger, 95], p. 731) found larger RTs in the incongruent condition compared to the congruent condition (RT unrelated prime < RT unfamiliar prime) which corresponds to the results presented here. Still, that difference presented itself as only a trend.
Thus, a significant difference revealed by the present data was unexpected (hypothesis 7, see 2.1.1). It suggests that the categorization to familiarity of prime and target itself leads to familiarity specific processes that facilitate the answer to the target in the congruent unprimed condition. This explains a smaller effect of repetition priming as the difference between the primed minus unprimed congruent condition. This is supported by the model of Bruce and Young [Bruce, 86c], in that for unfamiliar faces stored representations or FRUs are not yet available. Information processing of familiar and unfamiliar faces is different per se. Evidence that the human brain processes familiar and unfamiliar faces differently came from PET and fMRI studies [Dubois, 99] [Henson, 02] [Rossion, 01]. Different neural structures were found to be involved with respect to familiarity of a face. Henson et al. [Henson, 02] studied the effect of repetition priming and found a specific lateralization for familiar (right and left lateral fusiform region) and for unfamiliar (left fusiform region) faces. Rossion et al. [Rossion, 01] localized the discrimination with respect to familiarity of a face in the right ventral pathway. Thus, when prime and target are characterized by the same familiarity, the discrimination process itself might be facilitated. ERPs will bring more light into the debate and are discussed subsequently to the behavioural data. For a compilation of the differences between the repetition priming effects resulting from congruent and incongruent conditions see *Table 9* (p. 108). PEs revealed an effect of familiarity in that error rates for familiar targets were higher compared to unfamiliar targets. Thus, participants judged familiar people as being unfamiliar more frequently than they classified unfamiliar targets as famous. This replicates former results e.g. [Pfütze, 02] [Schweinberger, 95].

2.1.4.2 ERPs

2.1.4.2.1 P100

The P100 is supposed to reflect early visual processing e.g. [Pfütze, 02] [Itier, 02] and therefore, no effect of repetition priming or familiartiy was expected (hypothesis 2, see 2.1.1). Our results are consistent with these hypotheses and with previous studies e.g. [Boehm, 06a] [Pfütze, 02]. P100 was found to be particularly pronounced at O1/O2 electrode with a comparable latency over conditions. When hemispheric asymmetries had been tested, a slight lateralization to the right had been found. This is different to earlier results where such a hemispheric asymmetry was not found e.g. [Pfütze, 02] or at least had not been statistically analysed. In drawing further conclusions about what leads to this hemispheric difference the following was taken into account. The P100 as being correlated to visual spatial attention e.g. [Heinze, 94] is sensitive to face inversion [Linkenkaer-Hansen, 98] [Itier, 02] [Itier, 04a] and is related to the holistic processing of a face [Maurer, 02] and thus to the perception of the facial form. In a recent study Pobric, Schweinberger and Lavidor [Pobric, 07] investigated hemispheric differences in form-specific priming by repetitive transcranial magnetic stimulation (rTMS) within word-repetition priming. Their results establish the functional role of the right occipital cortex in form-specific priming. Form-specific priming relies on a visual word-form system localized in the right occipital lobe, which was in line with results from hemifield studies by Marsolek [Marsolek, 99]. Considering the way in which the stimuli in the Experiments of this thesis have been edited, it is conspicuous that the removal of background and the framing of the faces with a black background emphasizes the form of a face. At a latency of 100 ms face recognition starts with perception of a given face in a holistic way and seems at this latency not to be a domain-specific process. e.g. [Rossion, 99a]. This suggests transfer-ability from words as used by Pobric et al. [Pobric, 07] to the faces as used here. The sensitivity of especially the right occipital lobe to the form of a stimulus might explain stronger P100 for the right hemisphere. Moreover, the results in Experiment II and III will reveal the same right hemispheric lateralisation using stimuli edited in the same way. Also using (rTMS) Pitcher, Walsh, Yovel & Duchaine [Pitcher, 07] recently found the right occipital face area to be involved in especially the early stages of face processing, that was still, independent from repetition priming as it was found in the present experiment.

2.1.4.2.2 N170

The N170 was measured 170 to 180 ms after target onset and characterised as strong negativity at parieto-occipital electrodes. The peak latency or amplitude of the component was not affected by familiarity or repetition of the target, which conformed to hypotheses 2 (see 2.1.1). The N170 reflects perceptual processing like structural encoding of a face rather than retrieval of familiar faces. This result goes in line with previous studies e.g. [Deffke, 07] [Pfütze, 02] [Schweinberger, 95]. Moreover, in contrast to the study by Pfütze et al. [Pfütze, 02] a right hemispheric lateralization was only found as a hemisphere by familiarity interaction that disappeared when ERPs were testedseperately for familiar and unfamiliar targets.

2.1.4.2.3 Repetition priming effects

According to previous studies a repetition priming effect was hypothesized and was found to start subsequently to the foregoing components that are related to encoding processes marked by P100 and N170 (hypothesis 2, see 2.1.1). Experiment I revealed a repetition priming effect specific to familiar faces from 300 ms onwards, lasting until 580 ms. For unfamiliar faces the effect started 120 ms later. For familiar faces the repetition priming effect included two topographically distinguishable parts over time, according to the ERE and LRE. Both ERPs resembled those found in previous studies, as they were character-ized by an inferior-temporal negativity for the ERE and a central positivity combined with a prefrontal negativity for the LRE e.g. [Pfütze, 02] [Schweinberger, 95].

ERE

Beside the unfamiliar face mask, Experiment I was a replication of the Experiment by Schweinberger et al. [Schweinberger, 95]. The face mask was to impede perceptual-based priming. Thus, an familiarity specific ERE was hypothesized that is somewhat smaller compared to that found by Schweinberger et al. [Schweinberger, 95] and somewhat larger compared to Pfütze et al. [Pfütze, 02] as they used more than one intervening face between prime and target within a continuous-performance-paradigm (hypotheses 3 and 5, see 2.1.1). In *Table 8*, the results concerning peak amplitude of the ERE found by Schweinberger et al. [Schweinberger, 95] and Pfütze et al. [Pfütze, 02] are listed. The ERE found in the experiment at present, ranging from $M = 3.6$ µV at Fz to $M = -3.00$ µV at A2 (see *Table 6*), is smaller compared to Schweinberger et al. [Schweinberger, 95], ranging

from *M* = 4.00 µV at Fz to *M* = -4.00 µV at A2 and larger compared to Pfütze et al. [Pfütze, 02], ranging from *M* = 0.94 µV at Fz to *M* = -1.50 µV at M2.

Table 8: *ERE amplitudes (µV) by Schweinberger et al. (1995) and Pfütze et al. (2002)*

	Schweinberger et al. (1995)			**Pfütze et al. (2002)**		
	ERE 230-290 ms in µV			ERE 260-320 ms in µV		
	Fz	A1	A2	Fz	M1 (A1)	M2 (A2)
familiar	4.0	-3.0	-4.0	0.94	-0.00	-1,5
unfamiliar	2.7	-1.6	-2.7	-0.01	0.00	0.01

Neither a significant ERE concerning unfamiliar faces had been found by Pfütze et al. [Pfütze, 02], nor in the present Experiment. Hence, indicated by the absence of an ERE for unfamiliar faces, the ERE for familiar faces reflects representation-based priming while perceptual-based priming was impeded by the unfamiliar face mask. Results from Experiment I are consistent with Pfütze representation-based accounts of the ERE [Pfütze, 02] [Boehm, 06a] and as recently demonstrated by Bindemann, Burton, Leuthold & Schweinberger [Bindemann, 08]. The authors investigated the ERE (N250r) comparing vertically and horizontally stretched prime faces and unstretched face primes and demonstrated that the ERE (N250r) was independent from these image changes. This underpins the idea that the ERE reflects more than a visual overlap between prime and target, rather than indicating representation-based face recognition. The ERE was observed to be more pronounced in the right hemisphere, what is also consistent with previous results [Pfütze, 02] [Schweinberger, 95] [Schweinberger, 02a] [Schweinberger, 02b] [Schweinberger, 04] and supported by fMRI studies. For instance Henson et al. [Henson, 02] found decreased responses to repeated familiar faces particularly in the right lateral fusiform region. As in RTs, repetition priming in reference to ERP differences between primed and unprimed condition was modified by the congruence of prime and target concerning their familiarity. *Table 9* compiles the results, in this regard, concerning RTs, error rates and ERPs, ERE and LRE in particular. In contrast to results by Schweinberger et al. [Schweinberger, 95] congruence of familiarity between prime and target influenced ERPs for familiar faces from 340 ms onwards lasting until 420 ms for familiar and until 500 ms for unfamiliar faces. For familiar faces the direction of the influence, as reflected

by amplitudes changed at 380 ms, is interpreted as a marker for the transition from ERE to LRE. As the congruence of familiarity between prime and target did not affect the time segment where the ERE was determined, it has no further implications for Experiment II and III of the present thesis. Still, as such modulations were unexpected (hypothesis 7, see 2.1.1) it will be briefly discussed here.

Table 9: *Comparison of repetition priming effect concerning g prime- target congruence vs. incongruence*

Target's familiarity	**RT** (Repetition priming)	**Error rate**	**ERE 300-340 ms**	**LRE 460-500 ms**
familiar	con < incon $^{n.s}$	con < incon$^{n.s.}$	con < incon $^{n.s}$ (340-380 ms*)	con < incon$^{(*)}$ (380-420 ms*)
unfamiliar	con < incon$^{n.s.}$	con < incon$^{n.s.}$	-	con > incon** (420-500 ms**)

$^{(*)}$ p < .10 (Trend); *p < .05 ; **p < .01 ; ***p < .001; con: primed minus unprimed congruent; incon: primed minus unprimed incongruent; significancies refer to unscaled and scaled amplitudes (topographies)

The numerical difference of repetition priming effects from 340-380 ms as reflected by a smaller "congruent" compared to a larger "incongurent" repetition effect conformed to the results in performance data and might be brought in line with priming processes due to familiarity categorization itself in the unprimed condition. This can be supported by neural structures being activated in a familiarity specific way [Dubois, 99] [Rossion, 01]. Following the IAC model by Burton et al. [Burton, 90] it is assumed that the decision whether a person is familiar is made at the level of PINs (Figure 2, see 1.2.1.2.1). Carson and Burton [Carson, 01] demonstrated a repetition priming effect based on categorial relationship between prime and target and related this small effect to the level of PINs. When a PIN becomes activated some activation of this PIN is passed automatically to all the SIUs that are linked to that PIN by bi-directional links. Some activation will be passed back to all PINs connected to that SIU. In consequence to that any PIN that shares activation with that SIU with the original PIN will receive more activation. Hence, if activation is subsequently sent to this second PIN it takes less time for that PIN to reach the threshold level ([Carson, 01] pp. 1156). Familiarity of prime and target as a possible categorial relation-ship might cause faster and more efficient access to PINs of the target

even though it is not directly related to the prime. Still, empirical results are inconclusive and will need replication.

LRE

The LRE was significant to both familiar and unfamiliar faces, although smaller for unfamiliar faces. Topographies were not modified by familiarity of the target. This is in line with previous results e.g. [Boehm, 06a] [Herzmann, 04] [Pfütze, 02] [Schweinberger, 95] and with hypothesis 4 (see 2.1.1). Accordingly the LRE for unfamiliar targets might be caused by the repetition priming of visually derivable semantic codes like e.g. hairstyle or age. Not in line with previous results by Schweinberger et al. [Schweinberger, 95] is the influence of the prime - target congruence concerning familiarity that modulated the LRE for familiar at least in the beginning. From 380-420 ms the "congruent" repetition priming effect was somewhat larger than the "incongruent" repetition priming effect. Taking the IAC model by Burton et al. [Burton, 90] into account SIUs are connected to PINs by bi-directional excitatory links and within each pool by inhibitory links. If two faces are stored within a comparable level of semantic knowledge, as is the case for congruent prime – target combinations, when both are familiar or unfamiliar, inhibitory links between the SIUs might become active. Within-pool inhibition would eliminate repetition priming at the level of semantic information retrieval. Thus, when prime and target are of congruent familiarity, the difference between the primed and the unprimed condition turns out to be larger. When prime and target are at a different level of semantic knowledge as it is the case in incongruent prime-target combinations inhibitory links might become less important than bi-directional excitatory links from PINs to SIUs in that semantic information that is shared by an unfamiliar and a familiar face might increase in importance. Still, at the time of writing there are no comparable results.

2.1.5 Conclusion

Because the ERE may indicate FRU activation, but also priming of perceptual codes , in Experiment I a modified prime target technique was tested with the intention of eliminating perceptual codes by backward masking. According to the hypotheses as outlined in 2.1.1 results from Experiment I yielded a familiarity specific repetition priming effect using a facial backward mask. ERP differences between primed and unprimed targets revealed two components of the repetition priming effect - the ERE and the LRE.

As the ERE was confined to familiar faces it is concluded that it signals this residual activation of stored representations in LTM (FRUs) rather than perceptual-based short-term activation. Still, the specific impact of that mask type on the different processing stages remains unanswered as Experiment I only used one mask type. Thus, Experiment II of the thesis directly compared the impact of different mask types using the same repetition priming with backward masking paradigm.

2.2 Experiment II

2.2.1 Objective and hypotheses

The objective of Experiment II was to provide information about the impact of masking on different levels of face processing in general and about the dependence of the ERE on mask type in particular. Three different mask types, varying in attention demand followed the prime immediately to interfere with perceptual based processing (see 1.3.1.3): an unfamiliar face, a scrambled face and a grey rectangle as the non-mask type. It was hypothesized that a familiar face mask should interfere with both pictorial and structural codes of the prime face, a scrambled face mask with just pictorial codes, whereas the grey rectangle (non-mask) should not have an impact on the prime [Costen, 94]. Thus, the unfamiliar face mask should impede perceptual-based priming leaving residual, representation-based activity due to FRUs, to persist. The scrambled mask and the non-mask type are to reveal contributions of perceptual-based face priming to the repetition priming effect. A semantic decision task to famous (i.e. publicly known) people's faces was used. The same stimuli with respect to familiar stimuli and unfamiliar face masks had been used as in Experiment I for reasons of comparability.

Hypotheses were as follows:

1. For RTs repetition priming effects were hypothesized that vary according to mask type as revealed by previous results [Costen, 94]. The largest repetition priming effect was hypothesised for the non mask conditions, followed by a middle-sized effect for the scrambled mask conditions and the smallest effect was expected for familiar face mask conditions.
2. The impact of the mask type on different levels of face processing to the target as indicated by P100, N170, ERE and LRE, their latencies and amplitudes were analyzed. As P100 and N170 are associated with pictorial and structural

encoding, rather than retrieval, an intervening stimulus or a mask respectively should not affect these potentials. By contrast a graded pattern was hypothesized for the ERE as reflecting the activation of stored memory representations. An increasing impact of the mask should cause a systematic decrease of the ERE: If a familiar face mask interferes with the ERE then the smallest effect should be observed, leaving only a residual FRU activation in memory. If the results confirm what was hypothesized they support the conclusion drawn from Experiment I. A prime-target-paradigm with backward masking using an unfamiliar face mask was a suitable tool to obtain ERE as a sign of FRU activation.

3. Topographies for the repetition priming effect, according to mask type, which interfered with the prime and target, were analyzed. Distinguishable topographies across mask types, especially for the ERE, would support that without masking, two processes such as perceptual-based and representation-based processes overlap.
4. ERE should be characterized by a fronto-central positivity and occipito-temporal negativity, being distinguishable from the later priming component, the LRE, that is characterized by a central positivity and prefrontal negativity. The impact of mask type on the LRE was analyzed likewise.
5. Previous studies [Pfütze, 02] [Schweinberger, 95] revealed an ERE that was more pronounced on the right hemisphere. Accordingly in Experiment I a familiar specific right-hemispheric lateralization was found. Taken the discussion about lateralization into account, as outlined in 1.2.2.2 hemispheric differences are not hypothesized as being compulsory, but are at least controlled for the time segment in which ERE was determined and for the foregoing components N170 and P100.

2.2.2 Methods

Only methodological aspects that differ from Experiment I are described in the following. For methodological aspects that are equivalent to Experiment I please see 2.1.2.

2.2.2.1 Participants

Experiment I involved 22 participants, but, because of technical problems in data acqui sition, six participants had to be excluded. Thus, Experiment II involved the remaining 16 participants, 10 women and 6 men. All were between the ages of 19 and 35 years (M = 24.31 years SD = 4.93). Fourteen participants were strongly right-handed (index of handedness < 60). Two participants achieved an index of handedness> -20 and had to be classified as left-handed [Oldfield, 71]. All participants had normal or corrected-to-normal visual acuity.

One week before the experiment participants answered the questionnaire shown in Appendix D to ascertain whether they were able to identify a celebrity's face by name. This questionnaire was an advanced version of the questionnaire used in Experiment I (names labelled with "I / II" or "II" are used in Experiment II). It contained 232 names, 230 names of celebrities and 2 fictive names to control the fidelity of the answers. People who failed to recognize more than 15% (> 34 items) of the celebrities listed in the questionnaire were excluded. Two celebrities' names had to be excluded from the experiment, because they had been scored as unfamiliar by half of the people that answered the questionnaire.

2.2.2.2 Stimuli and Apparatus

The stimuli used were the black-and-white portrait photographs of familiar people from various areas (e.g. politics, entertainment, sports) that had already been used in Experiment I (see Appendix C), supplemented by pictures obtained from the internet. In contrast to Experiment I all stimuli had had their background-removed. The faces including the face mask-stimuli were shown on a black-background framed within an area of 105 pixels wide x 216 pixels high, corresponding to 3.7 cm x 4.41 cm stimulus size. This corresponded to a visual angle of 2.64° horizontal x 3.15° vertical at the viewing distance of 80 cm. Adobe Photoshop™ was used to edit the scrambled mask stimuli. Ten pictures were sliced into 36 pieces, and randomly recomposed. It was still possible to recognize individual parts of the face (see *Figure 11*). For the non-mask condition a grey rectangle sized as specified above, terminated the prime face. Mean luminance of the pictures was M = 720 Lux (SD = 193 Lux). A fixed chin rest was used while the EEG was recorded. As the semantic task required a nationality decision (German vs. international) half of the pictures were portraits of German celebrities, and the other half portraits of international celebrities. International

celebrities resemble the German familiar faces as close as possible with respect to approximate age, gender, general portrait style, and profession. Stimuli included photographs of 228 faces, 146 men and 82 women respectively. Faces were further subdivided into six sets of 36 faces per block (the remaining 12 faces were used as practise trials). The assignment of faces to experimental condition was counterbalanced in respect to gender, and profession. The remaining faces were used as practise trials.

2.2.2.3 Procedure

Experiment II was designed to compare performance and ERPs for only familiar faces, depending on prime and mask type. The same paradigm as in Experiment I was used. For details of the arrangement, i.e. trial sequence and feed back, of the experiment see Experiment I and *Figure 5*. In contrast to Experiment I the mask that followed the prime face varied from the unfamiliar face mask, scrambled mask and non-mask (grey rectangle) as *Figure 11* exemplifies. Exclusively familiar stimuli had been used for both primes and targets. In reference to the conditions in Experiment I, the unprimed condition in Experiment II was always congruent concerning familiarity of prime and target. Participants were shown sequences of three pictures and decided by two-choice key presses whether the third picture (target stimulus) represented a German or an international famous person. They were asked to respond as quickly and accurately as possible with the left or right index finger. The assignment to the response keys was reversed in half of the trials. For the instruction given to the participants see Appendix F.
A total of 216 prime-mask-target-sequences were shown, and short breaks after each 40 trials were allowed. Twelve practise trials were conducted twice, at the beginning of the experiment and after the assignment to the response keys were changed. In addition four practise trials preceded the 36 trials at the beginning of each block. Practise trials were not subsequently used.

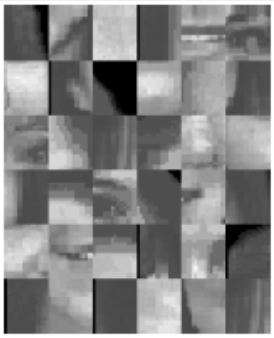
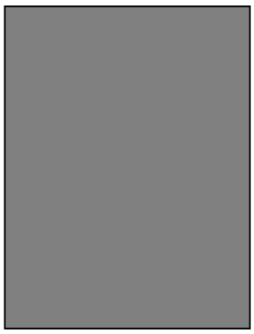
unfamiliar face mask	scrambled mask	non-mask (grey rectangle)
		

Figure 11: *Mask types used in Experiment II*

Sizes equal the width by height as originally used in the experiment and was the same for primes and targets. For exact trial sequence see Figure 5 Experiment I. Ten different scrambled faces and 80 different unfamiliar face masks were used in a randomized order.

This experiment was designed to compare responses to familiar target faces preceded by six kinds of prime-mask combinations:

A) the same familiar face masked by an unfamiliar face mask (FACE-P)

B) a different familiar face masked by an unfamiliar face mask (FACE-U)

C) the same familiar face masked by a scrambled face mask (SCRA-P)

D) a different familiar face masked by a scrambled face mask (SCRA-U)

E) the same familiar face masked by a grey rectangle or non-mask (NON-P)

F) a different familiar face masked by a grey rectangle non-mask (NON-U)

The nomenclature of the six conditions in summary is shown in *Table 2* (see 1.5.2, p. 77). The different mask types were presented block wise and the sequence of the blocks was randomized across subjects. The prime conditions were presented in randomized order. This was to eliminate any predictive value of the prime type for the target stimulus. Thus, both repeated and unrepeated primes were equiprobable and were equally likely to be followed by German or international target faces, respectively. There were 36 trials for each condition. The assignment of the right or left index finger to single stimuli was reversed for 8 of 16 participants. Target faces appeared only once as targets and were reused as primes in the conditions B, D, F in the second experimental part, after

assignment to response keys changed. Therefore, in the unprimed condition a given pair of faces was used only once in order to avoid episodic priming. 10 scrambled face masks and 80 unfamiliar face masks had been used randomly.

2.2.2.4 Performance, EEG - recording, statistical analyses

Responses had been scored and EEG had been recorded in the same way as in Experiment I. For details see outlines in Experiment I. ANOVAs with primed measures including the within-subject variables mask type (unfamiliar face mask, scrambled face mask and non-mask) and repetition priming (primed versus unprimed) were performed. To test the mask effect, pair wise comparisons were performed for primed and unprimed targets separately and for differences of primed minus unprimed stimuli. The latter was performed using unscaled (differences in mean amplitude) and scaled (topographic differences) analyses.

2.2.3 Results

2.2.3.1 Behavioural Data

An inspection of PEs (*Figure 12* and *Table 10*) shows that they varied with priming conditions in a similar way as RTs did, with no evidence of a speed-accuracy trade-off. Both RTs and PEs did show a graduated pattern according to the mask type that intervened prime and target. Priming effect decreased with increasing impact of the mask.

2.2.3.1.1 Reaction times (RTs)

RTs show the smallest repetition priming effect for the face mask, M = 213.19 ms (SD = 70.62), a medium effect for the scrambled mask, M = 261.89 ms (SD = 83.85) and the largest for the non-mask, M = 288.76 ms (SD = 83.3). The ANOVA revealed a significant effect of repetition priming, F (2, 30) = 190.14), $p < .001$, and a weaker but significant mask type effect, F (2, 30) = 3.99, $p < .05$. An interaction of mask type by repetition priming was found, F (2, 30) = 18.10, $p < .001$. Bonferrroni-corrected pair wise comparisons revealed that, the effect of repetition priming was significant for all mask types, for the face mask, F (1, 15) = 145.80, p< .001, the scrambled mask, F (1, 15) = 156.07, $p < .001$, and non-mask, F (1, 15) = 192.22, $p <.001$. Differences in repetition priming effects between face mask and scrambled mask, F (1, 15) = 20.69, $p < .001$, face mask and non mask, F (1, 15) = 29.84, $p < .001$ revealed significance. The difference between the repetition priming effect for scrambled and non mask types failed to reach

significance, F (1, 15) = 4.02. Testing the mask type effect pair wise comparisons within the primed conditions revealed significant differences between the face mask and the non-mask, F (1, 15) = 15.81, $p < .01$, and the scrambled and the non-mask, F (1, 15) = 8.46, $p < .05$. Within the unprimed conditions the mask type effect reached significance between the face and scrambled mask, F (1, 15) = 15.60, $p < .01$, and the face and the non-mask, F (1, 15) = 7.20, $p < .05$.

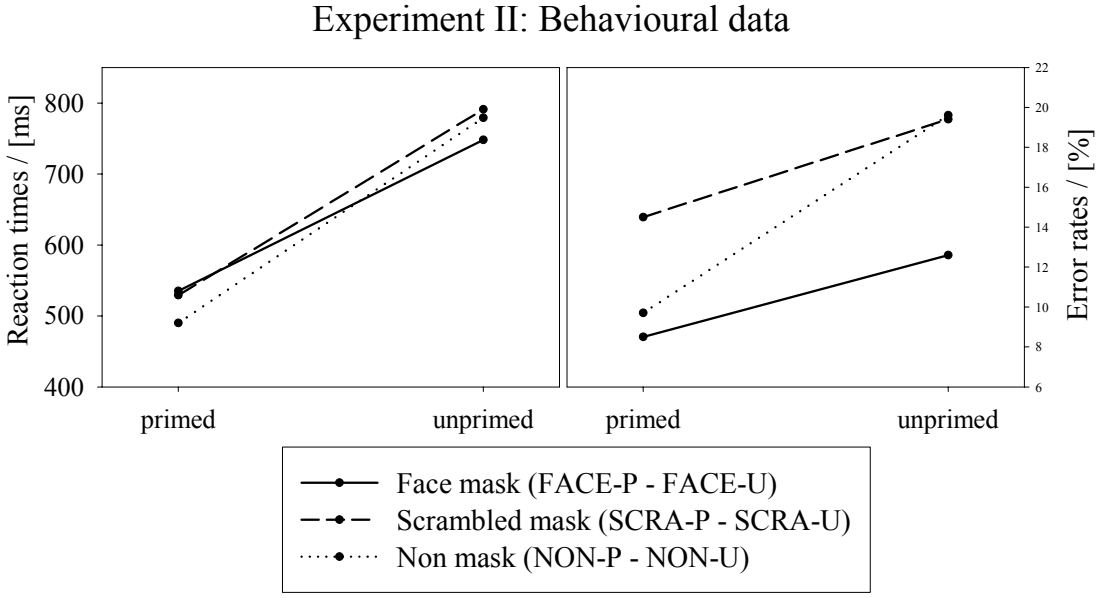


Figure 12: *Experiment II: Left: Mean RTs and Right: PEs in Experiment II*

2.2.3.1.2 Percentage of errors (PE)

PEs show the smallest repetition priming effect for the face mask, M = 4.16 % (SD = 5.55), a medium effect for scrambled mask, M = 5.03 % (SD = 7.80), and the largest for the non mask, M = 9.89 % (SD = 9.67). An overall ANOVA revealed a significant effect of repetition priming, F (2, 30) = 26.52, p < .001, and a significant effect of mask type, F (2, 30) = 12.06, p < .001. The interaction mask type by repetition priming was not significant, F (2, 30) = 2.72. Accordingly the repetition priming effects per intervening mask type did not differ. Testing the mask effect within the primed conditions, significances were found when the scrambled mask was compared with unfamiliar face mask, F (1, 15) = 6.20, p = .01, and non-mask, F (1, 15) = 11.49, p = .01. Within the unprimed conditions the comparison between unfamiliar face mask and scrambled face mask, F (1, 15) = 23.89, p = .001, and non-mask, F (1, 15) = 10.00, p = .01, reached significance.

Table 10: *Experiment II: Mean RTs and PEs in Experiment II*

Type of target an prime	**Mean RT / ms (SD)**	**PE (SD)**
Unfamiliar face mask		
Primed (FACE-P)	535 (117)	**9 (7)**
Unprimed (FACE-U)	748 (62)	**13 (7)**
Priming effect (FACE-P - FACE-U)	213	**4**
Scrambled mask		
Primed (SCRA-P)	529 (113)	**14 (6)**
Unprimed (SCRA -U)	791 (61)	**19 (8)**
Priming effect (SCRA -P - SCRA -U)	262	**5**
Non-mask (grey rectangle)		
Primed (NON-P)	490 (115)	**10 (7)**
Unprimed (NON -U)	779 (74)	**20 (9)**
Priming effect (NON -P - NON -U)	**289**	**10**

FACE-P = face mask/ target primed; FACE-U = face mask/ target unprimed; SCRA-P = scrambled mask/ target primed; SCRA-U = scrambled mask/ target unprimed; NON-P = non mask/ target primed; NON-U = non mask/ target unprimed

2.2.3.2 Event related Potentials (ERPs)

ERPs towards primed and unprimed faces can be seen in *Figures 13* and *14*. The figures contain ERPs accordant to the different mask types from 200 to 800 ms shown by different lines. Time period and electrodes that are displayed are the same as for Experiment I. An effect of repetition priming, mask type as well as an interaction repetition priming and mask type can be seen from 220 ms onwards and lasted until reactions are performed. *Tables 13* and *14* compile the results of ANOVAs until 700 ms. Detailed description is given in the following. Difference waves are calculated between the second and the first presentation to reveal the repetition priming effects per mask condition (see *Figure 15*).

2.2.3.2.1 P100

P100 for target faces was quantified with mean amplitude measures in the time segment 80 to 130 ms. In addition ANOVAs of peak latency as well as peak amplitude were performed relative to O1 and O2 electrode. As shown in *Table 11* differences in latencies and amplitudes appeared between primed and unprimed target faces and the different mask

conditions. Only at O1 peak latency differed significantly between the mask types, F (2, 30) = 5.04, $p < .05$. Longest latency was seen for face masked primes, M = 110.5 (SD = .70), followed by scrambled masked primes, M = 109.0 (SD = 1.41), and non-masked primes with the shortest latency, M = 105.5 (SD = .70). Pair wise comparisons failed to reach significance, $F < 2$. There were no effects of repetition priming or masking.

Table 11: *Experiment II: Mean peak latency (L in ms) and amplitude (A in μV) for P100*

	P100			
	O1		O2	
	L (SD)	A (SD)	L (SD)	A (SD)
FACE-P	111 (20)	4.1 (2.8)	107 (19)	4.5 (2.3)
FACE-U	110 (20)	4.0 (3.1)	107 (18)	4.4 (2.4)
SCRA-P	110 (20)	3.4 (2.9)	104 (19)	3.9 (2.5)
SCRA-U	108 (20)	3.6 (3.4)	104 (18)	4.1 (2.8)
NON-P	105 (20)	4.0 (3.3)	104 (18)	4.5 (2.7)
NON-U	106 (20)	4.1 (3.4)	105 (19)	3.9 (2.6)

FACE-P = face mask/ target primed; FACE-U = face mask/ target unprimed; SCRA-P = scrambled mask/ target primed; SCRA-U = scrambled mask/ target unprimed; NON-P = non mask/ target primed; NON-U = non mask/ target unprimed

Hemispheric differences were validated for the mean amplitude, comparing electrodes belonging to the left and the right hemisphere. As indicated by peak amplitudes listed in *Table 11* there are hemispheric differences, showing larger amplitudes over the right (O2), M = 4.2 μV (SD = .29), compared to the left (O1), M = 3.9 μV (SD = .29), hemisphere. This was validated by comparing the mean amplitudes according to the left and the right hemisphere. A significant main effect of hemisphere was found, F (11, 165) = 3.94, $p <$ .01, which was not influenced by mask type or repetition priming.

2.2.3.2.2 N170

N170 amplitude was measured as average voltage between 150 and 220 ms. Analysis of mean amplitudes in this time segment yielded no effects of repetition priming, mask type or interactions of both. Peak latency and amplitude, measured at PO9/PO10, as the most representative for this potential are summarized per condition in *Table 12*. Neither at PO9 nor at PO10 peak latency was a function of repetition priming or mask type. Peak

amplitude was affected by mask type at PO9 and PO10, *F*s (2, 30) = 8.30 and 8.05, *p*s < .01, when primed and unprimed targets were collapsed. Peak amplitude at PO9 and PO10 was smallest for face-masked primes, *M* = 2.15 μV (*SD* = .10), followed by scrambled-masked primes, *M* = 3.05μV (*SD* = .23), and non-masked primes with the largest amplitude, *M* = 3.10μV (*SD* = .37). Pair wise comparisons revealed significance at PO9/PO10 for the face mask and the scrambled mask, *F*s (1, 15) = 11.76 and 14.26, *p*s < .01, and the face mask compared to the non-mask *F*s (1, 15) = 8.16 and 11.33, *p*s < .05. The comparison of scrambled and non-mask failed to reach significance, *F* < 1. There was neither an effect of repetition priming nor an interaction between masking and repetition priming in peak amplitudes.

Hemispheric differences were validated for the mean amplitude, revealing a significant main effect of hemisphere, *F* (11, 165) = 4.64, *p* < .01. The interaction of repetition priming and hemisphere, *F* (11, 165) = 4.45, *p* < .001, reflected the preponderance of the right hemisphere for primed targets, *F* (11, 165) = 7.42, *p* < .001, compared to unprimed targets, *F* (11, 165) = 3.22, *p* < .05.

Table 12: *Experiment II: Mean peak latency (L in ms) and amplitude (A in μV) for N170*

	N170			
	PO9		PO10	
	L (SD)	A (SD)	L (SD)	A (SD)
FACE-P	165 (21)	-2.0 (3.3)	163 (23)	-2.2 (3.4)
FACE-U	160 (16)	-2.2 (3.7)	164 (22)	-2.2 (3.2)
SCRA-P	164 (21)	-2.9 (3.5)	164 (27)	-3.0 (2.8)
SCRA-U	164 (18)	-2.9 (4.0)	165 (20)	-3.4 (4.0)
NON-P	164 (21)	-3.2 (3.1)	165 (22)	-3.1 (3.6)
NON-U	162 (16)	-2.6 (4.1)	164 (22)	-3.5 (3.3)

FACE-P = face mask/ target primed; FACE-U = face mask/ target unprimed; SCRA-P = scrambled mask/ target primed; SCRA-U = scrambled mask/ target unprimed; NON-P = non mask/ target primed; NON-U = non mask/ target unprimed

2.2.3.2.3 Repetition priming and mask effects

To evaluate repetition priming effects to target faces mean amplitude measures were quantified in 12 adjacent 40 –ms time segments from 220 to 700ms. *Table 13* and *14*

contain the Bonferroni-corrected results of ANOVAs performed per time segment. *Figures 13* and *14* show ERPs for the three mask types. For clarity of inspection figures for primed target faces and unprimed target faces are shown separately. Repetition priming effects are highlighted by *Figure 15* where the difference waves (primed minus unprimed targets per mask type condition) are diagrammed. Primed faces elicited an increased positivity or decreased negativity at the vertex, whereas at prefrontal sites the polarity of the effect reversed. These effects were maximal around 400-500 ms and lasted until the end of the recording epoch. Repetition priming affected the early transient component that corresponds to the ERE, which is particularly well visible as fronto-central positivity and temporal-parietal negativity from 260 until 380 ms. Subsequently repetition affected the late component corresponding to the LRE, characterised by a parieto-central positivity and prefrontal negativity lasting until 700 ms, particularly visible at Pz. Overall ANOVA revealed an effect of masking and repetition priming from 220ms onwards lasting until 700ms. Repetition priming reached a maximum in time segments from 260 to 380ms. A quantitative graduation of the repetition priming effects according to mask type was visible across time segments and most evident for the ERE. This was validated by the interaction of mask by repetition that was significant from 220 ms onwards and reached a maximum in time segment from 260-300 ms. Pair wise comparisons revealed the smallest repetition priming effects for face masked conditions, starting from 220 ms and remaining significant until time segment 460-500 as well as 580-620 ms and 660-700 ms.
In *Table 14* the results of pair wise comparisons of repetition priming effects according to mask types are compiled. Differences between face masked repetition priming effects and scrambled as well as non-masked repetition priming effects were significant from 220 ms throughout the recording epoch. Scrambled and non-masked repetition priming did not differ significantly, Fs < 2.50. *S*eparate analyses of the effect of mask type on primed and unprimed targets were performed (*Table 13*) Whereas for the primed targets mask type affected mean amplitudes significantly from 220 ms onwards, for unprimed targets mask type affected mean amplitudes 80 ms later from 340 to 580 ms and only when the face masked condition is compared to the non mask condition.

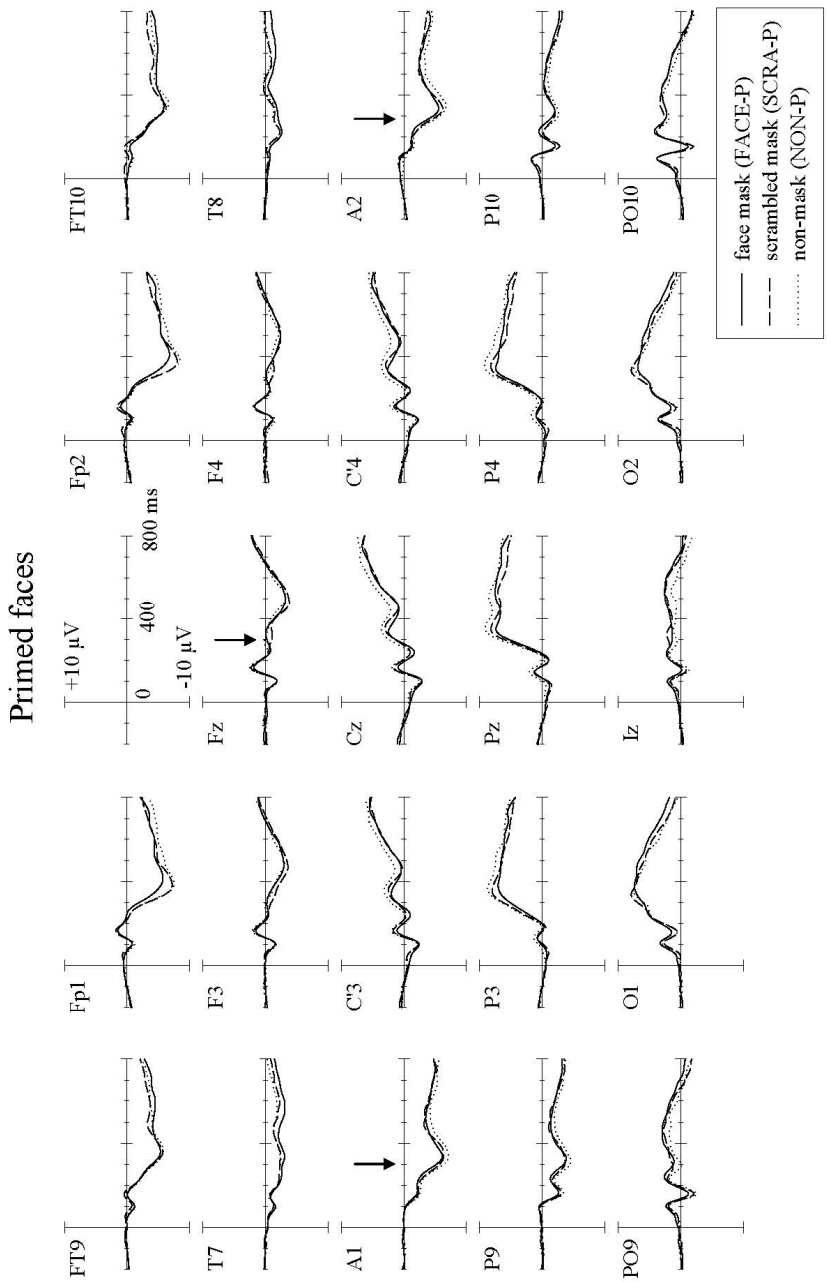


***Figure 13**: Experiment II: ERPs for face masked, scrambled masked or non-masked primed targets*

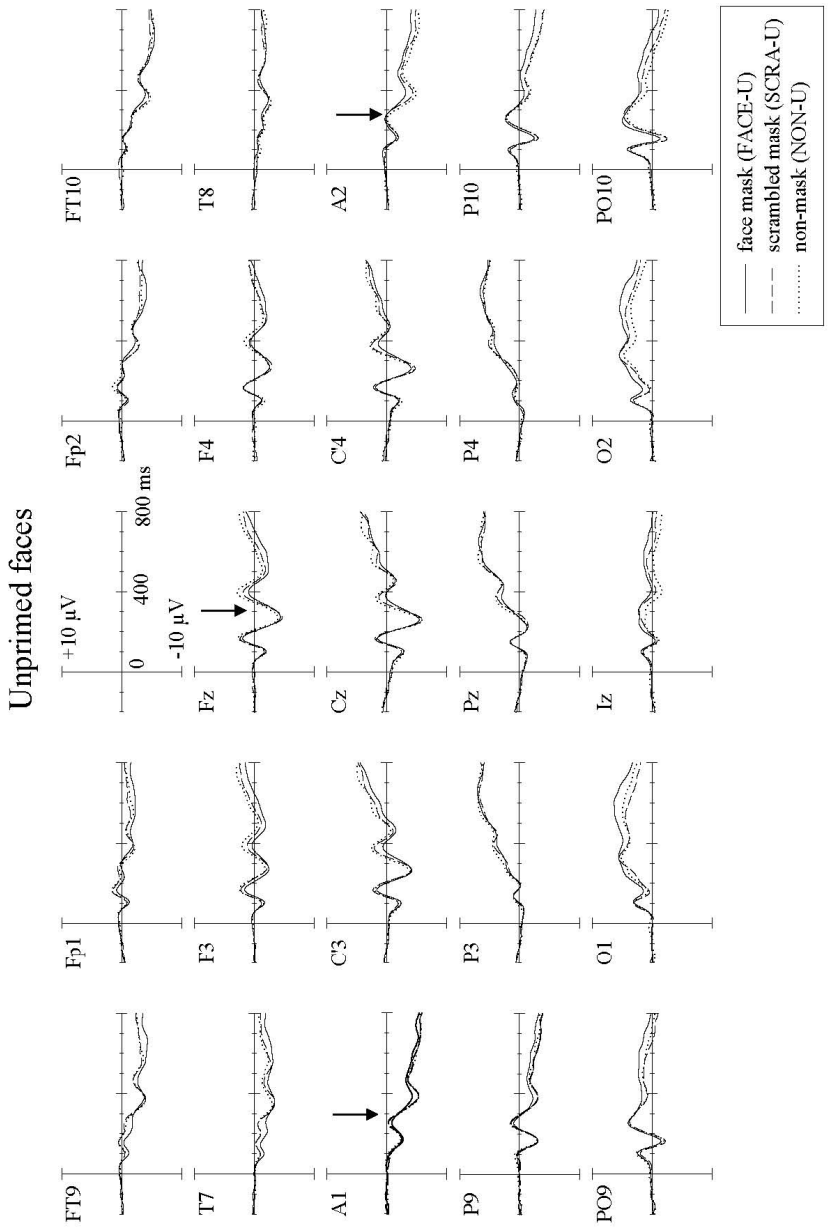


***Figure 14**: Experiment II: ERPs for face masked, scrambled masked or non-masked unprimed targets*

Table 13: *Experiment II: Results of the ANOVAS for amplitude measures of the ERP components*

		Time segments (ms)												
Source	df	80-130	150-220	220-260	260-300	300-340	340-380	380-420	420-460	460-500	500-540	540-580	580-620	620-660	660-700
All conditions:															
Mask	54, 810		2.15$^{(*)}$	3.23**	7.02***	11.42***	9.97***	6.19**	4.61***	3.57***	2.50*	2.81**	3.12**	2.81**	3.34**
Repetition	27, 405			19.20***	37.46***	38.65***	32.30***	17.70***	12.50***	8.11***	4.07**	3.76**	4.59**	3.76**	5.62**
Mask x Repetition	54, 810			6.46***	10.67***	7.32***	5.68***	5.46***	5.16***	5.03***	3.21**	2.30*	2.53**	2.30*	3.01**
Priming effect:															
Face mask	27, 405			5.44**	14.49***	18.87***	13.91***	8.30***	6.53***	4.57**			2.72*		4.14**
η_p^2				.27	.49	.56	.48	.36	.30	.23			.15		.21
Scrambled mask	27, 405			15.25***	34.71***	32.22***	20.84***	12.43***	9.47***	5.52**	2.84*	3.36*	3.77**	3.72*	4.08**
η_p^2				.50	.69	.68	.58	.45	.38	.27	.16	.18	.20	.20	.21
Non-mask	27, 405			16.43***	27.06***	24.67***	21.37***	14.57***	11.24***	9.42***	5.64**	3.58**	4.17**	3.58**	5.09**
η_p^2				.52	.64	.62	.59	.49	.43	.39	.27	.19	.21	.25	.25
Primed :															
Face - Scram	27, 405			9.54***	17.05***	19.64***	16.71***	9.49***	6.72***	4.03*					
Scram - Non	27, 405				2.42$^{(*)}$	3.41*			2.92$^{(*)}$	4.18**	2.92$^{(*)}$				
Face - Non	27, 405			9.05***	19.53***	21.87***	18.18***	11.06***	8.64***	7.54***	4.57**	3.21*	3.47*	3.21*	3.71*
Unprimed :															
Face - Scram	27, 405														
Scram - Non	27, 405														
Face - Non	27, 405					3.00*	4.32*	3.95*	2.93$^{(*)}$	3.92**	3.40*	4.05*	4.47*	4.05$^{(*)}$	4.09*

$^{(*)}$ $p < .10$ (Trend); *$p < .05$; **$p < .01$; ***$p < .001$; Bonferroni-corrected α - level for pairwise comparisons; not significant (n.s.) F-values not listed; η_p^2 = explained variance (effect size); FACE-P = face mask/ primed; FACE-U = face mask/ unprimed; SCRA-P = scrambled mask/ primed; SCRA-U = scrambled mask/ unprimed; NON-P = non-mask/ primed, NON-U = non-mask/ unprimed

Table 14: *Experiment II: Results of the ANOVAs for difference waves (mean amplitudes, topographies) Experiment II*

		Time segment (ms)												
Source	df	80-130	150-220	220-260	260-300	300-340	340-380	380-420	420-460	460-500	500-540	540-580	580-620	620-660	660-700
Amplitudes of difference waves:															
Face - scram	27, 405			7.17***	14.27***	10.07***	6.72***	5.70**	5.40**	4.60**	3.13*	3.33*	3.49*	3.31*	3.07
Face - non	27, 405			9.09***	13.74***	8.81***	7.27***	6.85***	6.54***	7.67***	4.87***	2.90*	3.13*	4.16**	3.91**
scram - non	27, 405														*
Topographies of difference waves:															
Face - scram	27, 405			3.08(*)	6.10***	5.44***	3.75*	3.36(*)	3.27*	3.96**	2.58(*)	2.64(*)	3.18*	3.16*	2.97(*)
Face - non	27, 405			3.48*	6.28***	4.90***	3.22(*)	2.75(*)	2.81*	3.62**			2.62(*)	3.43*	3.54*
scram – non	27, 405														

(*) p < .10 (Trend); *p < .05, **p < .01 ; ***p < .001 all data Bonferroni-corrected for pairwise comparisons; not significant (n.s.) F-values not listed; FACE-P = face mask/ primed; FACE-U = face mask/ unprimed; SCRA-P = scrambled mask/ primed; SCRA-U = scrambled mask/ unprimed; NON-P = non-mask/ primed, NON-U = non-mask/ unprimed

2.2.3.2.3.1 Early repetition effect (ERE)

The ERE as a temporally limited modulation appeared around 260 ms peaked around 300 ms and disappeared at 380 ms. As displayed in *Figure 15* especially on temporo- parietal sites and most evident from about 260 to 300 ms the ERE is modulated by mask type. The ERE reveals a graduated pattern which is characterized by the smallest potential when a face mask intervened between prime and target. Accordingly for face masked repetition priming effects the explained variance was 49%, for scrambled masked effects 69% and for non-masked effects 64%. Pair wise comparisons of the repetition priming effects in this time segment revealed significant differences between face masked repetition priming effects and scrambled as well as non-masked effects (*Table 14*). The difference between scrambled and non-masked ERE did not reach significance, $F < 1$. A comparison of the ERPs per mask type separated by primed and unprimed conditions (*Figures 13* and *14*) revealed that in this time segment the mask effect is more evident for ERPs to primed faces, this is confirmed by pair wise comparisons of mean amplitudes according to mask type within primed or unprimed conditions. Here the differences reached significance for primed faces only.

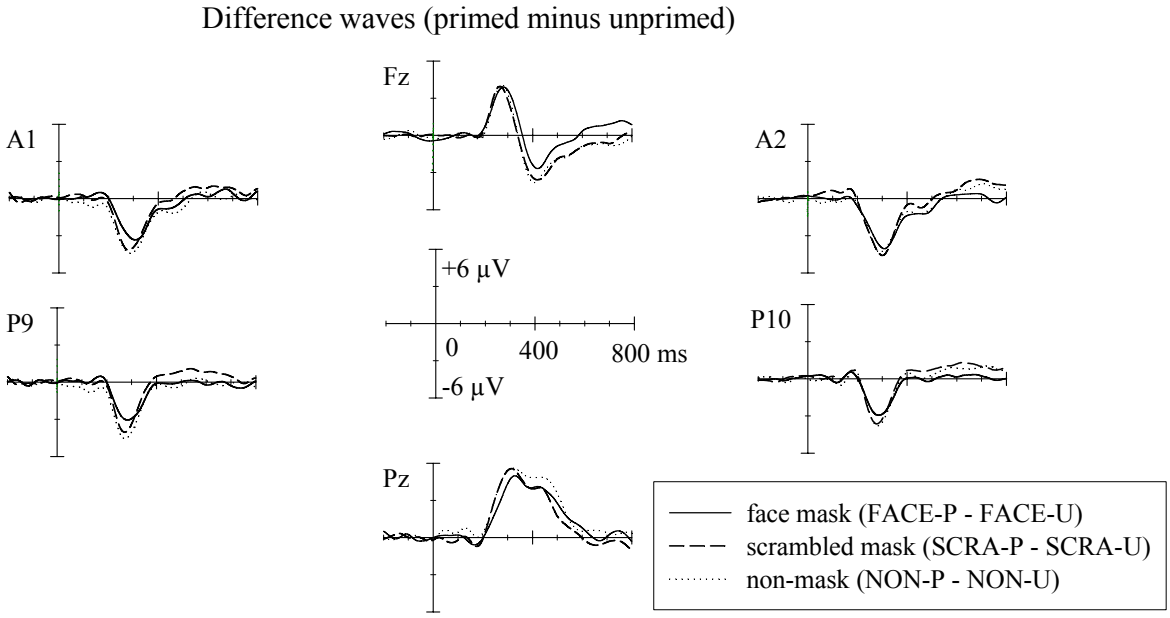


Figure 15: *Difference waves (primed minus unprimed) for face masked, scrambled masked or non-masked condition*

Hemispheric differences in repetition priming effects:

Overall ANOVA revealed a main effect of hemisphere lasting until the end of the recording epoch. Thus, lateralization was not restricted to the time segment 260-300 ms, where the ERE was determined. F-values reached a maximum in time segments from 300 to 380 ms, *F*s (11, 165) = 6.29, 6.04 and 4.89, *p*s < .001. Furthermore an interaction hemisphere, mask and repetition priming was present from 220 ms onwards, lasting until 500ms, and was highly significant in the time segment 260-300 ms, *F* (22, 330) = 4.13, *p* < .001. In this time segment hemispheric effects in mean amplitudes of difference waves where highly significant in all mask conditions, when prime was masked by a face, a scrambled face and a non-mask, *F*s (11, 165) = 15.46, 16.84 and 14.33, *p*s < .001. Still, lateralization for face-mask and scrambled mask conditions reflect a right hemispheric effect, whereas the ERE in the non-mask conditions revealed a left hemispheric preponderance. This is exemplified at peak amplitudes at A1/A2 (*Table 15*).

Table 15: *Experiment II: Mean peak latency (in ms) and amplitude (in µV) for the ERE*

	ERE					
	Fz		A1		A2	
	L(SD)	A(SD)	L(SD)	A(SD)	L(SD)	A(SD)
FACE-P-FACE-U	281 (29)	4.8 (2.5)	299 (29)	-3.8 (1.9)	306 (24)	-4.4 (2.2)
SCRA-P-SCRA-U	273 (25)	4.9 (2.9)	290 (25)	-4.6 (1.3)	304 (23)	-5.1 (1.8)
NON-P-NON-U	282 (29)	5.0 (3.2)	285 (25)	-5.1 (1.6)	296 (24)	-4.9 (2.2)

FACE-P = face mask/ target primed; FACE-U = face mask/ target unprimed; SCRA-P = scrambled mask/ target primed; SCRA-U = scrambled mask/ target unprimed; NON-P = non mask/ target primed; NON-U = non mask/ target unprimed

ERE– Peaks and latencies:

This experiment was designed to analyse the ERE in relation to the impact of specific mask types intervening between prime and target. An inspection of the ANOVA results outlined above and compiled in *Table 13*, reveals the strongest repetition effects and mask effects, as well as mask by repetition priming interaction, in time segments 260-340 ms. This suggested determining the peak of the earlier modulation in the repetition effects from 260 to 340 ms. In doing so a fronto-central maximum at the Fz electrode at 270 to 280 ms was found. Results are summarized in *Table 15*. Peak amplitudes of the ERE reflect a

graduated pattern of the ERE according to the impact of mask type. Showing a peak for the non-mask type that was somewhat larger compared to the ERE peak for the scrambled mask type, which itself was larger compared to the face mask type. At the same latency the temporo-occipital amplitudes revealed a similar graduation in negativity as found at A1. This systematic increase of the ERE according to the impact of the mask was significant, F (2, 30) = 6.11, $p < .01$. Still, only the difference between the face mask and the non-mask was qualified by pair wise comparison for A1 F (1, 15) = 10.57, $p < .01$. This was not significant for A2 or Fz electrode, Fs < 1.14. There was no mask effect concerning latencies of the ERE.

2.2.3.2.3.2 Late repetition effect (LRE)

In *Figure 15* difference waves reveal the late positivity that begins around 340 ms as diagrammed at Pz. The prefrontal negativity can be seen best at Fp1/Fp2 in *Figures 13* and *14*. Comparing repetition priming per mask types the later component was differently sized. This is especially well detectable around 400 ms, and characterized by a larger amplitude in the non-mask and scrambled mask conditions compared to the face mask condition. Post-hoc comparisons revealed for the face mask condition highly significant repetition priming effects from 340-500 ms and decreased, but were still significant from 580-620 and 660-700ms. For the scrambled mask, as well as non-mask types, repetition priming effects were highly significant from 340-500 ms and diminished thereafter. Accordingly the explained variances were highest in time segment 340-380 ms, for face mask 48 %, for scrambled mask 58 % and non-mask 59%. In *Table 14* the results of pair wise comparisons of repetition priming effects according to mask types reveal significant differences between face masked repetition priming effects and scrambled, as well as non-masked repetition priming effects, until 500 ms. Scrambled and non-masked repetition priming did not differ significantly, Fs < 1.

*S*eparate analyses of the effect of mask type on primed and unprimed targets were performed. In contrast to the time segment where the ERE was determined, mask type affected mean amplitudes for both, primed and unprimed targets, when face mask condition was compared to the non-mask condition. Pair wise comparisons of face mask and scrambled mask condition revealed significance in the primed conditions only.

2.2.3.2.3.3 Topographic analysis

The first set of analysis was to separate the early from the late portion of the repetition priming effect on the basis of their topographies over time segments. To find this dissociation differences waves (primed minus unprimed) for each mask type in the consecutive time segments from 220 ms to 700 ms were used. When topographies (*Figure 16, Table 14*) are inspected the ERE is marked by a positive aspect in mid-frontal regions. The LRE with a beginning around 340 ms was more pronounced in posterior central regions lasting until 600 ms. Statistical analyses were performed for each mask condition separately.

Concerning the face mask condition it was found that topographies changed from segment 260-300 to 300-340 ms, F (27, 405) = 6.71, $p < .001$, from 300-340 to 340-380 ms F (27, 405) = 5.47, $p < .01$ and again from 340-380 to 380-420 ms, F (27, 405) = 3.04, $p < .05$. Subsequent epochs from 420 ms to 700 ms were topographically indistinguishable. Difference waves for the scrambled mask condition showed the same and even higher significant picture. Topographies were found to be qualitatively different from 260-300 to 300-340 ms, F (27, 405) = 13.84, $p < .001$, from 300-340 to 340-380 ms F (27, 405) = 9.64, $p < .001$ and again from 340-380 to 380-420 ms (F (27, 405) = 3.53, $p < .05$. Subsequent epochs from 420 ms to 700 ms did not show a difference. Analysis for the non-mask condition yielded the same results with similar F-values as found for the scrambled mask condition: from 260-300 to 300-340 ms, F (27, 405) = 12.14, $p < .001$, from 300-340 to 340-380 ms, F (27, 405) = 9.31, $p < .01$, and again from 340-380 to 380-420 ms, F (27, 405) = 3.06, $p < .05$. Subsequent epochs from 420 ms to 700 ms had been indifferent. To determine which time segment best represents the LRE, time segment 260-300 ms which corresponds to the ERE, was compared to consecutive time segments. For all mask conditions the highest F-value was reached when 260-300 ms was compared to 340-380 ms: for face mask condition, F (27, 405) = 9.09, $p < .001$, for scrambled mask condition, F (27, 405) = 15.38, $p < .001$, and for the non mask condition, F (27, 405) =15.04, $p < .001$. In time segment 340-380 ms paired comparisons of unscaled mean amplitudes reached highest effect sizes (η_p^2) compared to the subsequent time segments (*Table 13*). Thus, time segment 340-380 ms was chosen to represent the LRE best and thus topographically displayed in *Figure 16*.

In a second set of analyses using pair wise comparisons between the topographies of difference waves according to different mask conditions it was determined whether the repetition effects showed mask specific topographies.

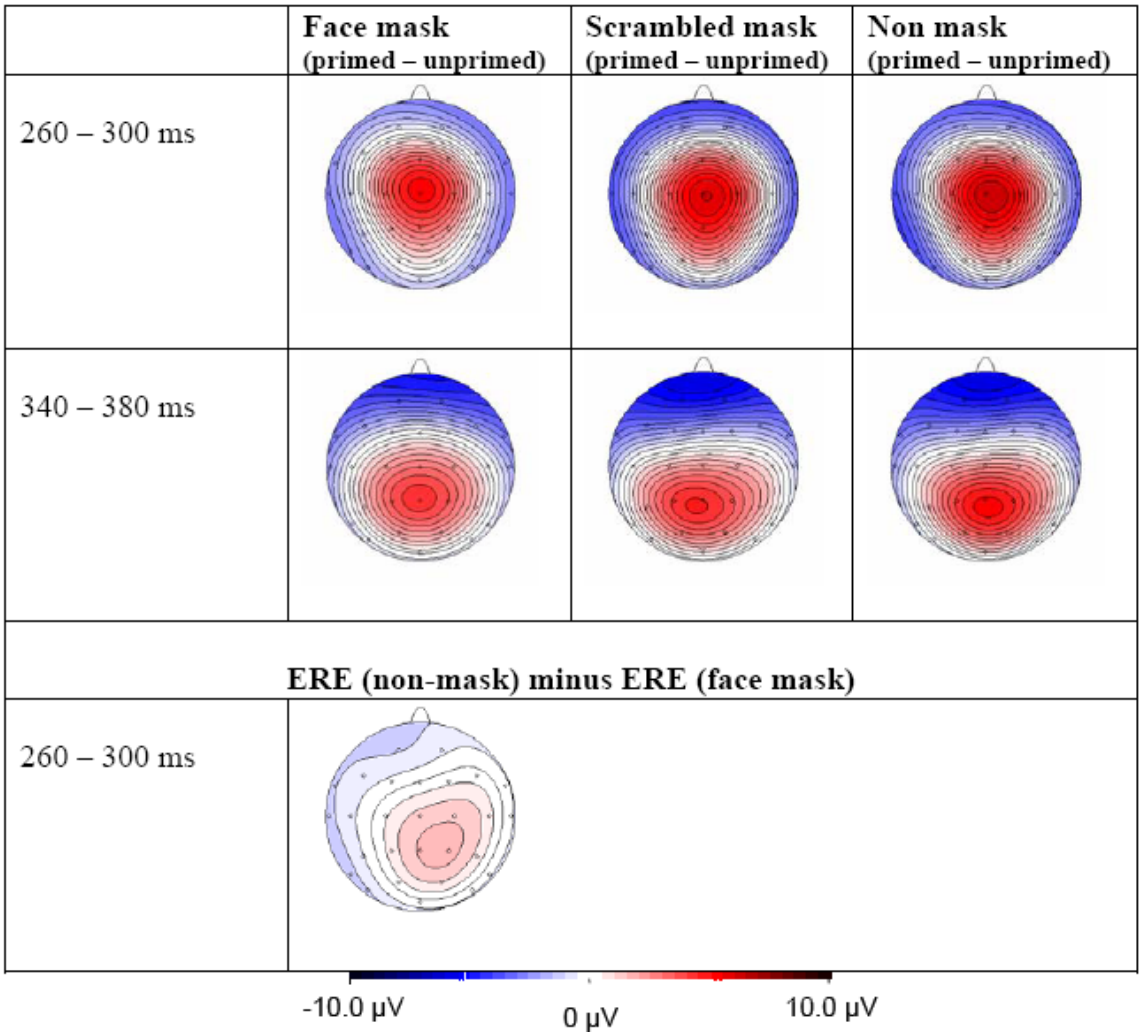


Figure 16: *Experiment II:* ***Top****: Voltage maps of ERP difference waves between primed and unprimed conditions showing ERE in time segment 260-300 ms and LRE in time segment 340-380 ms.* ***Bottom:*** *Voltage maps of ERE difference waves between the ERE resulting from non-masked conditions minus the ERE resulting from face mask condition (perceptual-based part of the ERE). Spherical spline interpolation was used. Equipotential lines are separated by 0.50 µV.*

Results are compiled in *Table 14*. When topographies in time segment 260-300 ms are inspected the weakest repetition priming effect (the most positive at Fz to the most negative value at A1) for the face mask condition 8.4 µV is conspicuous (for peak amplitudes in this time segment see also *Table 15*). For the scrambled mask condition a

middle 9.3 μV effect can be seen compared to the strongest effect of 10.0 μV for the non mask condition. This pattern continues until 700 ms. In addition a slight left hemispheric dominance in the time segment 260-300 ms is obvious, especially for the non mask condition as revealed when hemispheric differences had been analyzed in 2.2.3.2.3.1. In time segment 260-300 ms pair wise comparisons confirmed differences in topography between the face mask condition and both the scrambled mask condition and the non-mask condition. Though these differences are significant from 220 to 500 ms and again from 580 to 700 ms it reached highest *F*-values in segment 260-300 ms. LRE in time segment 340-380 ms topographies differed significantly between the face mask condition and the scrambled mask condition, F (27, 405) = 3.75, $p < .05$, and between the face mask condition and the non-mask condition as a trend F (27, 405) = 3.22, $p < .10$. *Figure 16b* outlines the perceptual part of the ERE as reflected by the difference between the non-masked ERE minus the face masked ERE.

2.2.4 Discussion

Experiment II was designed to compare the performance data, and ERPs and in particular the ERE according to three different mask types following the prime: unfamiliar face (face mask), scrambled face (scrambled mask) and grey rectangle (non-mask). As demonstrated in Experiment I, repetition priming with backward masking was based only on facial representation stored in LTM when a face mask was used. In contrast to a scrambled face or a grey rectangle, i.e. non-mask type, an unfamiliar face mask resembles the prime face by perceptual codes. In Experiment II the impact of two different mask types on repetition priming was hypothesised to demonstrate representation-based priming superimposed by perceptual-based priming, by means of a scrambled face mask that interferes with mainly pictorial and by means of the non-mask that interferes neither with pictorial nor with structural activation of the prime face. Unmasked repetition priming is a combination of representation-based priming due to LTM and of perceptual-based priming due to short term activation [Boehm, 06a; Boehm, 06b].

2.2.4.1 Behavioural Data

In RTs systematical increase of repetition priming effects that is inversely proportional to the impact of mask type was hypothesized (Hypothesis 1, see 2.2.1). Descriptively the smallest repetition priming effect was found for the face mask, a medium sized for the

scrambled mask and the largest for the non-mask. Additionally, repetition priming speeded RTs significantly for all mask types, thus reconciling former results by Costen et al. [Costen, 94]. The graduated pattern of the repetition priming effects suggests when a familiar face was repeated the repetition priming effect might be based on its structural representations due to LTM, when the prime was masked by an unfamiliar face. When the prime was not masked the effect gains strength because of the additional and superimposed perceptual part of priming due to short-term activation. Post-hoc comparisons of the significant interaction of mask type by repetition priming revealed a different pattern of RTs for the primed and unprimed conditions. For primed targets differences in RTs for the non-mask type compared to the scrambled and the face mask type were both significant. Pair wise comparison of the scrambled and face mask did not yield significance. This is reflected by faster RTs for target faces preceded by non-masked primes. Scrambled and face masks interfered with repetition priming with respect to significantly slower RTs compared to the non-masked conditions. RTs for the scrambled mask were descriptively faster compared to the face mask, which did not reach significance. Compared to the primed condition where the mask type affected RTs by means of increased reaction times when an unfamiliar face masked the prime, the affect of mask types on RTs in the unprimed conditions was reversed. In the unprimed condition an unfamiliar face mask caused significantly faster RTs compared to a scrambled mask or a grey rectangle (non mask). The RTs for the scrambled and non-mask type did not differ significantly.

The following interpretation for faster RTs within the face mask (unprimed) condition has to be considered as a cautious attempt to explain this effect that, to my knowledge, has not been demonstrated before and requires replication. Following the IAC model by Burton et al. [Burton, 90] there are excitatory links between a person's PIN and SIUs and inhibitory links within each pool of SIUs (*Figure 2*, see 1.2.1.2.1). As both, prime and target are familiar faces, inhibitory processes might occur between them in the unprimed condition that cause longer RTs compared to primed conditions independently of the mask type. Beside inhibitory processes at the level of SIUs, some activation passes back to all PINs connected to a SIU. Thus, any PIN that shares the SIU note with the original PIN will receive some activation and will reach the activation threshold faster when activation is subsequently sent to this PIN [Carson, 01]. An unfamiliar face mask between prime and

target causes at least some activation on the level of PINs and share some global semantic information with prime and target. Thus, although below threshold, an unfamiliar face mask between prime and target might strengthen this small effect on the level of PINs which diminishes the effect of within-pool inhibition on RTs. This is finally reflected in faster RTs in the unprimed unfamiliar face mask condition.
The differences between the scrambled and the face mask in the primed condition, as well as between the scrambled and the non-mask in the unprimed condition, did not reach significance. Scrambling impedes the availability of featural information and the configural information of a face is completely discarded. Pictorial information, e.g. shading, graininess or texture properties of a face, remains available. Thus, a scrambled mask mainly interferes with pictorial codes, whilst a face mask interferes with structural and pictorial codes. A grey rectangle should neither interfere with structural nor with pictorial information of the prime. This implicates an impact on RTs according to mask type. Thus, lack of significance when a scrambled face mask condition is compared to a non-mask or a face mask condition might be due, on the one hand, to a Type II error caused by the relatively small differences in RTs with respect to mask types and the way in which they interact with the information provided by the prime face. On the other hand, this might be connected to some facial parts that were still visible in the scrambled mask (see *Figure 11*, 2.2.2.2). If that is the case then more than just pictorial information was provided by this mask type which resembled the properties of a face mask.
In general the RTs in this Experiment reconcile previous findings by Trenner et al. [Trenner, 04] and Martens et al. [Martens, 06] in that the main effects of masking and repetition priming as well as their interaction were significant. The difference is that, in this experiment, after masking a familiar face, which was presented for 17 ms or 34 ms and masked by a X-pattern mask presented for 17 ms [Trenner, 04] or a scrambled face mask presented for 50 ms [Martens, 06] repetition priming on this subliminal level of facial processing disappeared in RTs. These results will be discussed in the following chapter in reference to ERPs.
PEs were lowest for the face mask type compared to the scrambled and non-mask type. An interaction of repetition priming and mask type was not significant. Even though, comparable to RTs, priming effects were found to be descriptively smallest for the face mask and highest for the non-mask type, they did not differ significantly. When the primed

condition is considered separately PEs for the scrambled mask were significantly higher compared to PEs for the face mask and the non-mask type. Taking RTs into account participant's answers to targets preceded by scrambled masked primes were as fast as in the face mask condition but there answers were significantly more error prone for the scrambled mask type. As the scrambled mask provides facial information based on features that are fragmentary visible as facial parts this mask type seems to have a distracting impact on the task that had to be performed with respect to the target.

2.2.4.2 ERPs

2.2.4.2.1 P100

It is supposed that the P100 reflects early visual processing by means of the pictorial encoding of a stimulus e.g. [Pfütze, 02] [Itier, 02]. Therefore, neither an effect of repetition priming, as a correlate of memory processes, nor an effect of masking was hypothesized (Hypothesis 2, see 2.2.1). Masking was to interfere with repetition priming processes rather than the encoding of the target stimulus. Results confirm this hypothesis, as no main effects for repetition priming and mask type and no interaction of these variables in mean or peak amplitude were found. Concerning peak latency, a mask type effect was shown to be significant irrespective of repetition priming, reflecting a slight delay of peak amplitude for the face mask, followed by scrambled mask type and the non-mask showing the shortest latency. The effect was weak as pair wise comparisons failed to reach significance. A latency effect according to mask type in this early potential has not been reported before. Trenner et al. [Trenner, 04] and Martens et al. [Martens, 06] report a repetition effect concerning mean amplitudes from 100 ms after target onset onwards that was significant for unmasked targets. As ERPs are associated with face specific processes at the earliest from 160 ms onwards e.g. [Bentin, 96] [Schweinberger, 04] the effect found in these studies was interpreted as facilitation of relatively early discrimination between primed and unprimed stimuli, based on low-level feature comparisons [Martens, 06]. Former support was given by Schweinberger et al. [Schweinberger, 95], where a repetition priming effect was found in the P100 time segment, still significant only for unfamiliar faces. If the P100 is a correlate of early discrimination processes on a low visual level, this discrimination might have been impeded in the masked condition. According to the results in this experiment, the latency shift occurred irrespective of repetition priming. One explanation for longer latencies in the P100 amplitude when an unfamiliar face appeared immediately

after the prime face might be a longer refractory period, where the responsiveness of the P100 generating neural structures is reduced and unable to generate another impulse. As already seen in Experiment I a right hemispheric preponderance was found in P100, being independent of mask type or repetition priming. As outlined in the discussion of the P100 in 2.1.4.2, this may be due to the presentation of the stimuli, as the head form was presented on black background. The P100 is associated with perception of holistic aspects of a face and facial form e.g. I[Itier, 02] [Itier, 04a], while the perception of form-specific aspects was correlated to right occipital areas [Pobric, 07; Pobric, 07]. Moreover, right hemispheric lateralization concerning the occipital face area was found in early face processing [Pitcher, 07].

2.2.4.2.2 N170

According to hypothesis 2 (see 2.2.1) no effect of repetition priming, mask type or an interaction of both was expected, as the N170 is associated with encoding of a facial structure rather than the activation of facial representations in memory. The results concerning mean amplitude and latency of peak amplitude confirmed this hypothesis. This is in line with results by Deffke et al. [Deffke, 07] Pfütze et al. [Pfütze, 02] and Schweinberger et al. [Schweinberger, 95], while other studies found an effect of repetition priming on N170 [Campanella, 00] [Herzmann, 04] [Kloth, 06].
Concerning peak amplitude, there was a significant effect of mask type when primed and unprimed targets were collapsed. The effect of mask type is characterized by the systematic pattern, showing the smallest amplitude for a face mask compared to the larger amplitudes for scrambles and non-mask. Peak amplitudes were reduced the more the mask stimulus provided information that resembled structural information provided by the prime stimulus. That enables an adaptation of the neural structures responsible for N170 generation resulting in the smallest peak amplitude when an unfamiliar face mask followed the prime face [Kovács, 05] [Kovács, 06].
A right hemispheric lateralization was found that was more pronounced for primed, as compared to unprimed faces. A right hemispheric lateralization in N170 was also found by numerous previous studies e.g. [Pfütze, 02] [Rossion, 03a]. According to Rossion et al. [Rossion, 03a] this right hemispheric lateralization signs the face-specificity of this component. Likewise, Pfütze et al. [Pfütze, 02] found this component more pronounced in the right hemisphere, while names were associated with a left hemispheric lateralization.

2.2.4.2.3 ERPs of masked repetition priming

Repetition priming started from 220 ms onwards and lasted until the end of the recording epoch. While in the studies by Trenner et al. [Trenner, 04] and Martens et al. [Martens, 06] repetition priming effects in ERPs disappeared after masking a familiar face prime beyond 200 ms, in a recent ERP study by Henson, Mouchlianitis, Matthews & Kouider [Henson, 08] familiar specific repetition effects occurred between 300 – 500 ms. In these studies the prime was presented on a subliminal level and masked by a X-pattern mask, a scrambled face or a scrambled inverted face. *Table 16* compiles the results of significant interactions of mask type by repetition priming in the present experiment.

Table 16: Masked repetition priming effects / Experiment II

Masked priming	**RT**	**P100**	**N170**	**ERE** Peak: Fz/A1	**LRE**
Latency	face < scrambled face < non scrambled = non	no masked priming*	-	-	-
Peak am-amplitude (η_p^2)	-	-	no masked priming*	face < scrambled face < non scrambled = non	-
Mean amplitude	-	-	-	-	face < scrambled face < non scrambled = non
Topo-graphy	-	-	-	-	face ≠ scrambled face ≠ non scrambled = non

*main effect mask type effect found for P100 latency and for N170 peak amplitude: non < scrambled < face mask type; face = repetition priming effect - face mask condition; scrambled = repetition priming effect - scrambled mask condition; non = repetition priming effect - non mask condition

Including the ERE and the LRE the interaction between masking and priming reached significance for the first time from 220 onwards and continued until 500 ms. This masked priming effect did show the hypothesized graduated pattern with respect to its effect sizes (Hypotheses 2, see 2.2.1), in that the smallest repetition priming effect was found for the face mask, a medium repetition priming effect for scrambled mask type and the largest the non-mask type. Pair wise comparisons validated the difference for the face mask and the scrambled mask as well as the difference between the face mask and the non-mask type. The difference between the scrambled mask and the non-mask failed to reach significance. The differences of repetition priming effects according to mask type was qualified by

distinguishable topographies between face masked primes compared to scrambled masked and non-masked primes, whereas the topographies between the scrambled and non-masked type did not differ. As in Hypothesis 3 (see 2.2.1), this reconciles the assumption of two different superimposed processes as related to perceptual-based and representation-based priming.

ERE

The ERE peaked around 280 ms and was characterized as occipito-tempoal negativity and fronto-central positivity for primed, as compared to unprimed targets and is qualitatively different from the LRE. This confirms Hypothesis 4 (see 2.2.1). Mean amplitude as well as peak amplitudes of the ERE are systematically affected by mask type, showing the smallest amplitude for the face mask, medium amplitude for the scrambled mask and the largest for the non-mask. This reconciles the assumption that the non-masked ERE reflects a combination of at least two dissociable processes, one process due to representation-priming as activation within LTM and one process due to short-term activated perceptual-based memory while the face masked ERE is based on the activation of facial representations due to LTM. Peak latency of the ERE was not affected by mask type, suggesting that perceptual-based and representation-based processes co-occur. This implies an information flow in a cascade manner as postulated by McClelland [McClelland, 79]. Hence, perceptual-based and representation-based information might be processed in a parallel contingent way, with a continuous transmission of activation of STM to activation due to structural representations due to LTM. The topography of the face masked ERE differed from both, the non-masked as well as the scrambled masked ERE. This suggests that indeed, the face mask interfered with perceptual codes including pictorial and structural codes, of the prime face. The scrambled mask was to interfere with only pictorial codes and the non-mask mask type interfered with neither pictorial nor with structural codes and thus, the perceptual codes due to short-term activation remained available in both mask conditions. The topography of face masked ERE indicates representation-based face priming. Subtraction of the topography of the face masked ERE from the topography of the non-masked ERE described the perceptual-based part of the ERE (*Figure 16b*, see 2.2.3.2.3.3). The topographic difference of the face masked and the non-masked ERE indicates that, the underlying neuronal sources of perceptual-based and recognition-based priming are triggered at least by partially different neuronal sources. This might be due to

differently weighted activations within the STS or within the fusiform gyrus [Gobbini, 07] [Haxby, 00] and might be differently mediated by feedback from other areas as prefrontal [Leveroni, 00] [Okada, 00] and fronto-central areas [Itier, 02] [Jiang, 00] being associated with working memory processes.
Previous results did show different topographies for familiar and unfamiliar EREs when the prime was not masked within an immediate repetition priming paradigm [Herzmann, 04] [Schweinberger, 95]. An ERE for unfamiliar faces was attributed to perceptual-based priming as the recognition facilitation within a priming paradigm cannot at this point be based on stored representations [Boehm, 06a] [Boehm, 06b]. Still, a comparison of the ERE due to perceptual-based priming for unfamiliar faces and the perceptual-based part of the ERE caused by familiar faces might be misleading as some authors see unfamiliar face processing as a completely different process to familiar face processing [Hancock, 00] [Megreya, 06] [Megreya, 07]. With reference to topographic differences it is interesting that a right hemispheric lateralization was found for the face masked and the scrambled masked ERE, while the non-masked ERE was correlated with a left hemispheric preponderance, this is in line with Pfütze et al. [Pfütze, 02]. The subtraction of the face masked ERE from the non-masked ERE highlights a left-hemispheric preponderance of the perceptual-based part of the ERE on a descriptive level. Still, the conclusion that especially right hemispheric lateralization would signal the activation of representation-based priming cannot be drawn exclusively as this was also found for immediate repetition priming, when perceptual-based priming was not impeded e.g. [Schweinberger, 95]. Moreover, results concerning lateralization are inconsistent, for example Boehm et al. [Boehm, 06a] found a left hemispheric preponderance of ERP correlates of priming. Thus, to investigate lateralization results would require, on replication, an analysis by, for example, dipole source modeling.

LRE

The topography of the LRE shows a central positivity and a prefrontal negativity and was evident in all three mask conditions, which conforms to hypothesis 4 (see 2.2.1). The results concerning masked repetition priming are comparable to the results for the ERE. That is reflected by the systematic increase of the LRE as the impact of the mask decreases. Still, as Costen et al. ([Costen, 94] p. 245), have suggested “that masking must occur before decisions on the familiarity of the face are made”, masked priming effects on

the LRE are implausible. The masked priming effects in time segments where the LRE was determined might be due to the ERE and its overlap with the LRE. An inspection of the difference waves in *Figure 15* especially of the Pz electrode, where the overlap of the ERE and the LRE should be minimal, reveals a positive maximum around 320 ms. This reconciles the assumption of the IAC model by Burton et al. [Burton, 90] of continuous information output to the next processing stage. Following that the processing of semantic information as reflected by the LRE overlaps in time with prior processing stages, as activation of structural representations of a face.
In contrast to the time segment where the ERE was determined the difference between the non-mask and the face mask reached significance in the unprimed conditions. This difference was evident in RTs as well. According to the IAC model by Burton et al. [Burton, 90] it was explained by diminished within-pool inhibitory processes on the level of SIUs by additional PIN activation caused by the unfamiliar face mask (see 2.2.4.1).

2.2.5 Conclusion

Results from Experiment II indicate that repetition priming with backward masking by an unfamiliar face mask is an appropriate tool to extract an ERE that is based on the processing of facial representations stored in LTM while eliminating the availability of perceptual based information due to STM. Masked repetition priming effects were found in RT, ERE and LRE showing a graduated pattern of repetition priming effects, which was consistently the smallest for the face mask and the largest for the non-mask condition. Repetition priming decreased as the impact of the mask increased. On the level of structural encoding as reflected by P100 or N170 masked priming effects were not found. The face masked ERE was specific concerning topography compared to scrambled or non-masked EREs indicating two different sources of repetition priming: representation-based priming, as extracted by the face mask and the combination of perceptual-based and representation-based priming for the non- and scrambled masked condition. For the ERE the mask type affected primed targets only, leaving the unprimed condition unaffected by the impact of a mask. Thus, only the facilitation of the activation of structural representations within FRUs in the primed condition interfered with masking. This is in line with Costen et al. [Costen, 94], who localized masking effects on the level of structural encoding or FRU levels within the face processing system.

3 VIEWPOINT-DEPENDENCE OF REPRESENTATION-BASED FACE-PRIMING: PROPERTIES OF THE ERE

3.1 Experiment III

Experiment III addresses the question of viewpoint-dependence of the ERE as an indicator of stored representations of a face image. In Experiment I and II repetition priming with backward masking generated a familiarity specific ERE and showed a special topography when an unfamiliar face masked the prime face. This suggests that this residual activation can be brought in line with activation of facial representations. Thus, by using repetition priming with perceptual backward masking the ERE was validated as a reliable marker to evaluate the activation of the FRUs. Experiment III analyzed the ERE concerning its sensitivity to viewpoint changes by using the technique as tested in Experiment I and II. Based on the discussion of empirical results concerning viewpoint-dependence in face recognition and their theoretical interpretation as summarized in 1.3.4, stimuli in Experiment III were highly standardized concerning viewpoint (0° as frontal view and 90° as profile view) and external features of facial image. Hair was removed to focus on the internal features of a face. For the reason of standardization the stimuli material had to be learned prior to the experiment. Sixty-four initially unfamiliar stimuli from either frontal (32 faces) or profile (32 faces) were familiarized by classification to fictive hometowns (Rome or Paris) during a learning session (see 3.1.2.3.1). Approximately 24 hours after the learning session a two-part recognition session was conducted. The first part of the recognition session consisted of a recognition task in terms of a semantic decision, when viewpoint was changed or not changed from prime to target. After a short break the second part of the recognition session was conducted. It consisted of a familiarity decision task to test the familiar specificity of the ERE. Beside an ERE in the view-same and especially in the view-changed condition (part 1), an ERE that is confined to familiar faces (part 2) would provide additional evidence of the success of the learning session. Consecutively the experimental parts will be referred to as: ***Recognition session 1****:* Analysis of viewpoint-dependence and ***Recognition session 2:*** Analysis of familiar specificity. In the following, besides the objective and hypotheses, the methodological section will comprise the methodology of both parts, variations will be outlined. The description of the learning session is dedicated to the procedure of the experiment, because it was accomplished prior to the recognition session.

3.1.1 Objective and hypotheses

3.1.1.1 Recognition session 1: Viewpoint-dependence of the ERE

The objective of Experiment III was to analyze the sensitivity of the ERE to changes in viewpoint, which was the focus in recognition session 1. The generalization from one single familiar view (frontal or profile target), learned prior to the recognition session, to the corresponding unfamiliar view (profile or frontal prime) was tested. Using repetition priming with backward masking a familiar target face is primed by the same or its 90° changed view, which was not encountered before. As targets in recognition session 1 always were familiar, a semantic decision task (home town) was used. According to the Model by Bruce and Young [Bruce, 86c] FRUs contain an interlinked set of structural codes for distinct head angles reflecting configuration-based as well as feature-based information. FRUs become active when any view of a face that is familiar to the observer is seen. Thus, FRU activation is thought to be viewpoint-independent [Burton, 94] based on interlinked two-dimensional representations. This would be compatible with theories that assume face recognition as the encoding of both, feature-based as well as configuration-based information [O'Toole, 98] [Schwaninger, 02] that are retrieved dependent upon the angle of view change [Valentin, 01]. Different rotations to depth produce different configural and featural codes in memory, that become active even if the unfamiliar view is 90° changed related to the familiar view. Following Valentin et al. [Valentin, 01] face recognition across view changes from 0-30° should mainly rely on distinctive configural and above 40° on featural information. Previous studies demonstrated reduced recognition accuracy which was still above chance level after view changes of 90° (Valentin et al. [Valentin, 01] see *Table 1*) and fMRI studies that have found viewpoint-sensitive and viewpoint-independent regions in the fusiform cortex [Eger, 05] [Pourtois, 05]. Based on the theoretical assumptions and results, as previously outlined, an ERE should be still detectable when faces where primed with 0° or 90° deviance from their learned view. When compared to the EREs amplitude based on the repetition of the same view the ERE after view change should be present but smaller in size. Following Burton et al. [Burton, 99] attenuation of repetition priming across different images is caused by the reduction to the remaining similarities of two images after view change which causes a decrease in the strength of the links between FRUs and PINs (see 1.2.1.2.2). Concerning topography, an ERE that is indistinguishable with respect to the

same or changed view and to learning view would support the idea of consolidation of features and configuration, according to the different views, into a single representation – into FRUs. This would also reconcile the assumption of the integration of several viewpoint-dependent images e.g. [Bülthoff, 95] [Schyns, 93] and features [Schwaninger, 02] into a single representation. Theories that rely on multiple views of two-dimensional images and their interpolation alone [Bülthoff, 92] might have to be refused because at least two different views have to be encountered to afford face recognition from an unfamiliar viewpoint. Theories that rely on object-centred, three-dimensional representation, based exclusively on parts predict immediate viewpoint-invariance and therefore no effect of orientation disparity e.g. [Biederman, 87]. As they account for objects on a basic-category level they are less able to account for individual face recognition.

Hypotheses were as follows:

1. Repetition priming for frontal as well as profile target faces was hypothesized with respect to RT. When faces were shown repeatedly, RTs should be faster when the target face was primed by the same or the 90° deviant image presenting the identical person. When viewpoint has changed, repetition priming is hypothesized to be smaller compared to the unchanged condition [Boehm, 06b].
2. In ERPs the learning view should affect the P100 as being sensitive to physical variations in the stimuli, because mean luminance to profile targets was smaller compared to mean luminance for frontal targets (see 3.1.2.2). Previous results revealed the sensitivity of the N170 to structural differences of facial stimuli. Therefore a larger amplitude and a delay in latency for profile targets was expected due to an increased difficulty in encoding profile faces e.g. [Bentin, 96] [Itier, 02] [Schweinberger, 04].
3. Effects of repetition priming in ERPs, from about 200 ms until the end of the recording epoch, were hypothesised for frontal and profile targets [Itier, 04a]. The effect should be smaller, but still significant, even when the view from prime to target was changed. With regard to previous results no priming effect was expected for P100 and N170. The repetition effect should include two

topographically distinguishable modulations over time, according to the ERE and the LRE.

4. As in the foregoing Experiments and with regard to previous results the ERE is more positive at fronto-central and more negative at occipito-temporal sites for primed targets. When the viewpoint was changed, from prime to target, the ERE should yield a smaller but significant amplitude when compared to repetition with the same view.

5. Topographies of the ERE for changed and same views, as well as for frontal or profile targets are compared as they provide insights into the spatial configurations of intracranial current sources for configuration and feature-based information processing. Topographical indistinguishable EREs would indicate the integration of different views and features into a single representation reflected by comparable neural sources [Bruce, 86c] [Bülthoff, 95] [Schwaninger, 02].

6. With regard to previous results the LRE is characterized by a central positivity and a prefrontal negativity. This potential rather reflects the semantic component of face recognition. The LRE should not differ between changed and same views, because the same person is identified, even if the view changes from prime to target [Schweinberger, 02b].

7. As in Experiment I and II hemispheric differences are analyzed as previous results have demonstrated an ERE that is more pronounced in the right hemisphere [Pfütze, 02] [Schweinberger, 95]. fMRI [Pourtois, 05] and PET [Rossion, 00a] studies suggest that right hemispheric lateralisation is associated with configural processing and the processing invariant to viewpoint and processing of facial parts was found to be more pronounced in the left hemisphere. Thus, hemispheric asymmetries are analysed for the ERE and forgoing P100 and N170 with regard to view change and learning view.

3.1.1.2 Recognition session 2: Familiar specificity of the ERE

This experimental part was employed to test familiar specificity of the ERE and thus, to control the acquisition and retrieval of facial representations by analysis of performance data and of the ERE. Repetition priming with backward masking was used to demonstrate

an ERE that is confined to faces that had been learned prior to the recognition sessions (see 3.1.2.3.1). Beside the ERE as reflecting implicit memory processes, familiar (learned) and unfamiliar (unlearned) targets in the unprimed condition are compared to indicate explicit memory processes e.g. [Joyce, 05]. In the following the term familiar means learned or familiarised during the learning session, while unfamiliar includes faces that were not encoded before. With respect to the paradigm and the recognition task (familiarity decision) recognition session 2 of Experiment III is a replication of Experiment I of this thesis (see 2.1). Stimulus material consisted of unfamiliar faces that were learned from the profile and frontal view and unfamiliar frontal and profile faces of the same quality. As the recognition session 2 is due to the familiar specificity of the ERE the view between prime and target had never changed. A familiarity specific ERE would indicate the successful formation of facial representations in memory during the learning session. Furthermore, as already tested in recognition session 1, topographical differences between the ERE for frontal and profile targets were analyzed.

Hypotheses were as follows:

1. RTs should reveal a repetition priming effect that is larger for familiar compared to unfamiliar faces. Moreover RTs to familiar faces should be faster compared to RT to unfamiliar faces. In ERPs a repetition priming effect from about 200 ms until the end of the recording epoch is hypothesized. That means regarding previous results no priming effects were expected for P100 and N170. The repetition priming effect should include two topographically distinguishable modulations over time, according to an ERE and LRE.
2. According to previous experiments an ERE was expected, being more positive at frontal-central and more negative at occipito-temporal sites, for primed targets peaking around 300 ms. The ERE should be absent for unfamiliar faces which indicates the success of the learning session prior to the experiment (see 3.1.2.3.1).
3. The other subsequent topographically distinguishable modulation of the repetition effect is the LRE characterized by a central positivity and a prefrontal negativity. It should be detectable for unfamiliar faces as well, because of the visually derivable semantic information [Schweinberger, 95].

4. As already analyzed in recognition session 1, differences in ERPs caused by the learning view (frontal or profile) were analyzed. Differences at the stage of perceptual encoding were expected between profile and frontal presented target faces. Namely the P100 and N170 might differ between frontal and profile target faces because of visual differences. Topographies of the ERE for frontal and for profile targets were analyzed. Indistinguishable topographies would underpin the theoretical assumption of the integration of different views into a single representation. Because of the biophysical fact that different potential field distributions on the scalp indicate differences in the underlying neuronal sources. Differences, particularly in topography, would contradict the hypothesis of viewpoint-invariant representations of a face.
5. Hemispheric differences are analyzed as in the previous experiments.
6. The difference between familiar and unfamiliar targets in the unprimed conditions is to reveal the old/new effect with respect to FN400 and the LPC that signals familiarity and explicit recollection of a face (e.g. [Joyce, 05] see 1.4.1.1). This analysis was conducted only in Experiment III because the stimuli had been newly learned which may implicate the episodic retrieval of facial information due to the learning session.

3.1.2 Methods

3.1.2.1 Participants

For Experiment III, two of the original 24 participants had to be excluded because of technical problems in data acquisition and an additional 6 participants were excluded because of an error rate of more than 35% in the recognition session 1. The data used was from the remaining 16 participants who had all passed recognition sessions 1 and 2 for both parts of experiment III. Of the 16, 12 were women and 4 were men between the ages of 20.31 years, *M*=25.56 years, SD=3.52. Handedness was tested by a German version of the Edinburgh inventory. Apart from one participant with an index of handedness < -60, all participants were strongly right-handed with an index of handedness < 60 [Oldfield, 71]. All participants had normal or corrected-to-normal visual acuity. Concerning recognition session 2, all of the eight participants performed the familiarity decision task only to

frontal target faces and eight participants performed the task additionally to profile target faces, optionally depending on the degree of exhaustion of the participants.

3.1.2.2 Stimuli and Apparatus

The stimulus material was provided by Bülthoff and colleagues from the Max Planck Institute for Biological Cybernetics. The faces database (Cyberware™) consists of colour laser-scanned male and female heads shown from the frontal and left or right profile view. The hair, the back of the head and the cloth were not shown in the face models. A more complete description of this database can be found in Troje & Bülthoff [Troje, 96]. All pictures had had the background removed and were shown on a black background. Appendix E exemplifies the stimuli. This database was chosen because it consists of a huge body of male and female faces that are highly standardized with reference to viewpoint. External features, such as hair, were removed. The focus is on internal facial features apart from ears or general head shape. This is because of the special role that internal features play in recognizing familiar faces and in establishing facial representations [Bonner, 03a] [Ellis, 79]. All faces show the same neutral expression and are homogenized with regard to age and pictorial codes like luminance, contrast and colour. Prior to the experiment participants had to learn the stimuli (see 3.1.2.3.1). Faces were divided into fictive hometowns “Paris” and “Rome”. The learning session is described exactly in 3.1.2.3. “Paris”- faces resemble the “Rome”-faces as close as possible with respect to gender, approximate age, and general portrait style. Stimuli for recognition session 1 (semantic decision task) included a total of 168 faces. Sixty-four faces, 32 men and 32 women respectively, that had to be learned from the profile (16 left profile / 16 right profile) or frontal view. Sixty-four faces had been shown as unlearned views of the learned faces as primes. Forty unlearned faces had been randomly used as masks (profile and frontal). Left or right profile mask were used equivalent to the prime face. Stimuli for recognition session 2 (familiarity decision task) included a total of 292 faces: 64 learned faces, 40 mask faces randomly used, and 188 unfamiliar faces. Unfamiliar face stimuli were from the same database. All stimuli were software-edited using Adobe Photoshop™, converted to 8 bit pictures with 256 colours and a horizontal and vertical resolution of 256 pixels. The faces including the face mask-stimuli were shown on a black-background framed within an area 9.03 cm wide x 9.03 cm high, which equals a visual angle of 6.46° horizontal and 6.46° vertical on a viewing distance of 80 cm. ERTS® [Dutta, 95] served as

a experimental software for stimulus presentation and response recording. Mean luminance was *M* = 170 Lux (SD = 52 Lux) for all profile shown faces and mean luminance *M* = 690 Lux (SD = 99 Lux) for all faces shown from the frontal view. Profile and frontal target faces were presented block wise and data was analysed separately, to avoid possible effects of learning view in early potentials (P100) being ascribed to differences in luminance. The faces were further subdivided into eight sets to assign them to experimental conditions (with 28 faces each) was counterbalanced with respect to gender, view and hometown. The remaining eight faces were used as practise trials.

3.1.2.3 Procedure

3.1.2.3.1 Learning session

Participants were required to learn the 64 faces, half from the frontal and half from the profile view, by assigning them to fictive hometowns “Rome” or “Paris”. This classification was to facilitate encoding and recognition, and to control, as far as possible, the encoding level for the faces to be learned. The learning task was conducted approximately 24 hours before participants had to perform the recognition sessions. .The participants were seated in a dimly lit, sound attenuated room. The learning procedure was presented as an instruction on a computer screen as well as in paper form to give an overview of how the learning task is arranged (see Appendix G). The learning session was divided in four study phases of 16 faces each. A study phase was followed by a test phase (matching to sample task). The exact sequence of the learning session was as follows:

The learning session was divided into two parts of 32 faces. In each part 16 faces from the profile and 16 faces from the frontal view had to be learned. Each part consisted of two study-phases with eight faces each that were grouped in hometowns. During the study phase subjects were instructed to remember faces in order to recognize them subsequently. Each face was presented for 3000 ms with its fictive hometown simultaneously appearing, written underneath the picture. After a blank screen for 1500 ms the next picture appeared. No response was required. After eight faces per hometown, faces were presented altogether, lasting on the computer screen for 32 seconds. This was repeated once. After 16 (2 study phases) and 32 faces (4 study phases, 2 test phases), previous to a test phase, all faces studied so far were presented sorted by hometown. It could be aborted by participants key-pressing. During test phases participants had to perform a matching to sample task.

Meaning that they had to find the “Rome” or the “Paris” face from two faces presented simultaneously on the left and the right of the computer screen. Both, the target face and the distracter face had been studied before. Participants were instructed to indicate the target faces via key-pressing (left or right) compatible to the position of the target face. Only for the 32 face and the final 64 face test did participants have to achieve the learning criteria of 100%. All items had to be classified correctly twice. They were presented twice within a different arrangement (left or right with changing distracter faces). Responses were scored as correct if the appropriate key was pressed within a time window lasting from 300 ms to 30 seconds. Items that were answered incorrectly were appended until the answer was correct. Participants always received feedback about the correctness of their response or late reactions. It was signed as “correct” (written green), “false” (written red) or “late” (written yellow) appearing on the computer screen. The procedure was the same with the second part comprising the other set of 32 faces. When the second part was finished participants had a short break. To pass the final test they memorized printed copies of all faces according to hometown and view, on four different pages to provide the possibility to compare and classify the faces beside a computer screen. The learning task ended with an overall test (final test phase), which included 64 faces.

Overall each face was viewed at least eight times (including study and test) with an estimated presentation time of at least 83 s in total (including study phases with variable presentation time for 32-face presentation and test phases with an estimated reaction time of 1000 ms) on the computer-screen. Participants performed the learning task, on average within 90 minutes.

3.1.2.3.2 Recognition session 1: Viewpoint-dependence of the ERE

Before participants performed recognition session 1, they were required to perform the same matching to sample task as in the final test-phase of the previous days learning session (see 3.1.2.3.1). Error criterion was set again to 0%. Items that were answered as incorrect were appended until the correct answer was given. This was to recreate the connection between face and semantic classification and to reduce error rates. In favour of reducing error rates the disadvantage of possible episodic priming from the matching to sample task to the subsequent recognition session 1 and 2 was accepted. There was a half-hour break for electrode preparation between the matching to sample task and the

beginning of the recording. The sequence of recognition session 1 and 2 was chosen to be identical to recognition session 1. The viewpoint-dependence of the ERE was tested, which constitutes the main focus of Experiment III and was performed by every participant for frontal and profile targets. Recognition session 2 was for frontal faces and optionally profile targets depending on participant's exhaustion. For experimental reasons a semantic decision task rather than a familiarity decision task was chosen in recognition session 1, as the main focus was to be on the sensitivity of the ERE to changes in viewpoint and its modification by learning view. A familiarity decision task would have led to 16 conditions, instead of eight when a semantic decision task was used. EEG-recording during recognition session 1 and 2 was arranged in a dimly lit, sound-attenuated and electrically shielded chamber. After the electrodes were applied and prior to the experiment participants received written task instructions on a computer screen (see Appendix F). Two response keys were fixed 4 cm apart from each other at participant´s saggital midline. The repetition priming paradigm with backward masking as validated in Experiments I and II was applied (see 2.1.2.3). In recognition session 1 the answer to a semantic decision task about the hometown (Rome or Paris) of the target face ,as sampled before, was required. Participants were exposed solely to target faces that had been learned before. Prime faces were either the same as the target face or the unfamiliar profile or frontal view of the familiar target. Participants decided by two-choice key presses whether the target stimulus represented a "Rome" or a "Paris" face. They were asked to respond as quickly and accurately as possible with the left or right index finger. The relation of the target face to the prime face was not mentioned in the instructions. Participants received feedback on correct, incorrect, late or missing responses only during the practise trials. During actual trials just late responses (more than 4000 ms) or missing reactions were indicated on the computer screen.

Figure 17 is an example of a trial sequence for a primed but view-changed condition where a frontal face was preceded by its profile view. This is to give the reader an idea about the difficulty of the tasks. For the exact description of the trial sequence see Experiment I (see 2.1.2.3).

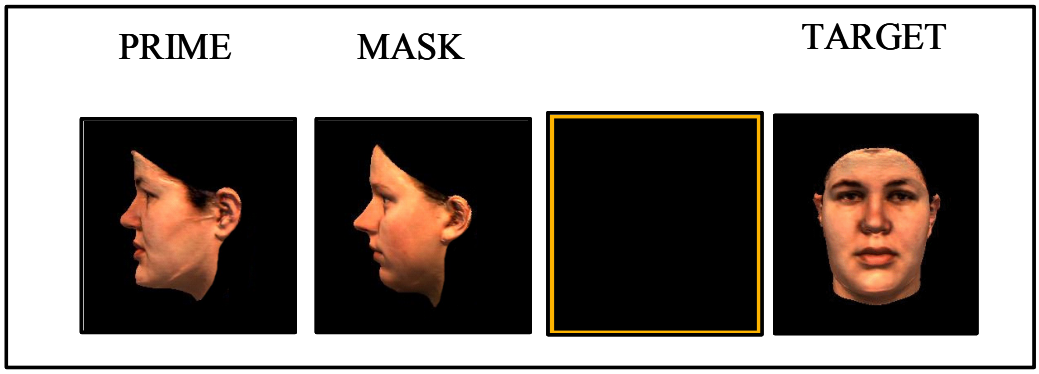


Figure 17: *Experiment III / Recognition session 1: Trial sequence primed / view-changed; (Note that the original size was 9.03 x 9.03 cm)*

A total of 224 prime-mask-target-sequences were shown. A short break after each 30 trials was allowed. The assignment to the response keys was reversed after 112 trials. 16 practise trials were conducted twice, at the beginning of the experiment and after the assignment to the response keys were changed. In addition two practise trials preceded the 28 trials at the beginning of each block. Practise trials were not subsequently used. This experiment was designed to compare responses to familiar target faces (frontal as well as profile, block wise presented) that were preceded by four kinds of primes:

A) same face, same view (FSP; PSP)

B) same face, changed view (FCP; PCP)

C) different face, same view (FSU; PSU)

D) different face, changed view (FCU; PCU)

Changed view represents a perspective that is always 90° deviant to the target view (frontal to profile and v.v.). Coding and nomenclature is presented in *Table 2* (see 1.5.2, p. 77). Conditions were presented in a randomized order. Primed (same and changed view) and unrprimed targets were equiprobable. The number of left profile targets equalled the number of right profile targets. There was no predictive value of the prime type for the target stimulus. There were 28 trials for each condition. For eight of the 16 participants the assignment of the right or left index finger per stimulus was reversed. Target faces appeared four times as targets (once per block) and were reused as primes once, after assignment to response keys changed. Twenty unfamiliar face masks per learning view were randomly used.

3.1.2.3.3 Recognition session 2: Familiarity specificity of the ERE

As before, repetition priming with backward masking was used in recognition session 2. A familiarity recognition task was used. Participants were presented with both, previously learned faces and unfamiliar faces, and were required to identify them by two-choice key - pressing. They were asked to respond as quickly and accurately as possible with the left or right index finger. The target-prime face relation was not mentioned in the instructions (see Appendix F). Participants received feedback to late responses (more than 1500 ms) or non responses. The same paradigm as in part 1, Experiment I and II was used. For the exact description of the trial sequence see Experiment I (see 2.1.2.3). For those eight participants who performed the familiarity decision task for frontal learned faces only a total of 112 prime-mask-target-sequences were shown. Short breaks after each 30 trials were allowed. The assignment to the response keys was reversed after 56 trials. Eight practise trials were conducted twice, at the beginning of the experiment and after the assignment to the response keys was changed (for other practise trial details see recognition session 1, 3.1.2.3.1). Eight participants performed the familiarity decision for both, faces learned from the frontal view and from the profile view. The number of trials listed was doubled, for these participants to 224 prime-mask-target sequences. This experiment was designed to compare responses to familiar target faces (frontal as well as profile) with responses to new target faces preceded by four kinds of primes:

A) the same familiar face (FFP; PFP)

B) a different unfamiliar (unlearned, new) face (FFU; PFU)

C) the same unfamiliar (unlearned, new) face (FUP; PUP)

D) a different familiar face (FUU; PUU)

Coding and nomenclature is presented in *Table 2* (1.5.2, p. 77). The perspective remained constant from prime to target while the familiarity decision task was performed. Target faces appeared twice as targets (once per block) and were reused as primes in the conditions B, D in the second experimental part, after assignment to response was keys changed. In the unprimed condition a given pair of faces was used only once in order to avoid episodic priming. Twenty unfamiliar face masks per learning view had been used randomly.

3.1.2.4 Performance

In recognition session 1 and 2 errors of omission (no keypress until 4000 ms or 1500 ms) and comission were recorded separately. Only responses more than 4000 ms had been scored as errors in recognition session 1 for reasons of the task's difficulty. RTs were calculated for correct responses only.

3.1.2.5 EEG-recording

The EEG was recorded with Ag/AgCl electrodes mounted in an electrode cap (Easy – Cap^{TM}; Falk Minow Services) at 62 scalp positions FPz, Fz, FCz, Cz, CPz, Pz, Oz, Iz, Fp1, Fp2, AF3, AF4, AF7, AF8, F1, F2, F3, F4, F7, F8, FT7, FT8, FT9, FT10, FC3, FC4, C1, C2, C3, C4, C5, C6, CP3, CP4, TP7, TP8, P1, P2, P3, P4, P5, P6, O1, O2, F7, F8, T7, T8, P7, P8, P9, P10, PO3, PO4, PO7, PO8, PO9, PO10, left (A1) and right (A2) mastoid. The A1 and A2 electrode were used as linked mastoids to provide an initial common reference. AFz served as ground. Recording the EEG with a linked-mastoid has to be critically remarked as it does not offer the opportunity to recalculate the reference electrodes. Linked mastoids can influence or even distort the data [Miller, 91b], when used without care. Therefore, A1 and A2 were excluded in later analysis. Electrode positions conformed to the modified international 10-20-System [Pivik, 93]. The outer ring from canthi to inion places electrodes 10% beyond the 10-20- System (see Appendix). Electrode impedances were kept below 10 kΩ and were typically below 5 kΩ. The horizontal EOG was recorded from the outer canthi of both eyes, located in the electrode cap at F9/F10 position. Consequently F9/F10 had to be excluded from further analysis. The vertical EOG was monitored from electrodes below the left and the right eye against FP1/FP2. The EEG was continuously recorded with a sampling rate of 250 Hz. Low-pass filters with zero-phase shift were set to 30 Hz. The time constant of the amplifier was 5 s, corresponding to 0.032 Hz. Offline epochs were generated that started from 200 ms before target onset until 4200 ms after target onset. Error trials were excluded. A second order Butterworth filter simulation with a 0.0531 Hz high-pass filter was performed with zero-phase shift on data. After that the average reference was calculated from all electrodes beside eye electrodes and linked mastoids. All trials were visually inspected for artefacts of ocular (e.g. blinks, saccades) and non-ocular origin (e.g. channel blockings or drifts). Trials with artefacts were discarded. The recording was then segmented into epochs of 200 ms before stimulus onset until 800 ms after stimulus onset. ERPs were then averaged separately for each

channel and for each experimental condition. Each averaged ERP was low-pass filtered at 10 Hz with a zero phase shift filter. At least 15 trials per average were involved.

3.1.2.6 Statistical Analysis

Statistical analysis was accomplished as in to Experiment I and II (2.1.2.6) and only variations are described here. Concerning recognition session 1, ANOVAs were performed with repeated measures including the within-subject (two-level) variables learning view (frontal vs. profile) and repetition priming (primed vs. unprimed) and view change (same vs. changed). Analysis of mean amplitudes was conducted with average referenced data on a subset of 58 electrodes. Thus, ANOVAS for ERPs included the additional factor electrode (58 levels). Bonferroni-corrected planned contrasts for repetition priming (comparison between primed and unprimed targets) were calculated for each learning view. ERPs were quantified with mean amplitude measures in the time segments 80-120 (occipital P100), 140-220 (occipito-temporal N170), in 14 adjacent 20 ms - time segments from 220 to 500 ms, 500-550, 550-600, 600-700 and 700-800 ms. If necessary to validate priming effects per time segment, one-tailed t-tests were performed for pair wise comparisons of the global field power, (GFP) [Lehmann, 80] [Lehmann, 84] in time segments where the effects had been found. GFP reflects the overall ERP activity (electrical strength, degree of hilliness) across the scalp at a given time. The numerical procedure to assess the GFP includes the scaling of average referenced voltages at all electrodes by their root mean square (RMS) of the sum of squared voltages. RMS voltage values are related to power measurements per condition and participant. Analysis of RTs and PEs as well as for peak latencies, peak amplitudes and of hemispheric differences of the P100, N170 and ERE had been performed analogous to the data in Experiment I and II. As previously for pair wise comparisons of repeated and unrepeated conditions, effect size in terms of explained variance (partial eta square - η_p^2) is provided per time segment (Cohen, 1988). Topographies of the difference waves (primed minus unprimed faces) in the view-same vs. view-changed condition for each learning view condition per time segment were analysed (as listed above) separately and pair wise compared. Furthermore, the specificity of topographies of repetition priming effects with respect to learning view had been analyzed. Concerning recognition session 2, ANOVAs were performed with repeated measures including the within-subject (two-level) variables learning view (frontal vs. profile), familiarity (familiar vs. unfamiliar) and repetition priming (primed vs.

unprimed). In case of a significant repetition by familiarity interaction, post-hoc comparisons were performed in order to analyse the difference of familiar and unfamiliar targets that corresponds to the old new effect (FN400 / LPC). Please note that when an overall ANOVA was performed in recognition session 2, only 8 participants were included, because only 8 participants performed the familiarity decision task to profile target faces. For further contrasts separated by learning view, 16 participants were included when performance and ERPs to frontal target faces were analyzed.

3.1.3 Results of recognition session 1: Viewpoint-dependence of the ERE

3.1.3.1 Behavioural Data

PEs and RTs to target faces are summarized in *Table 17* and *Figure 18*. An inspection of this data showed that, in contrast to RTs, not all PEs varied with repetition priming. Namely PEs in the unprimed condition for frontal targets (same view) and for profile targets (changed view) were lower compared to the primed conditions.

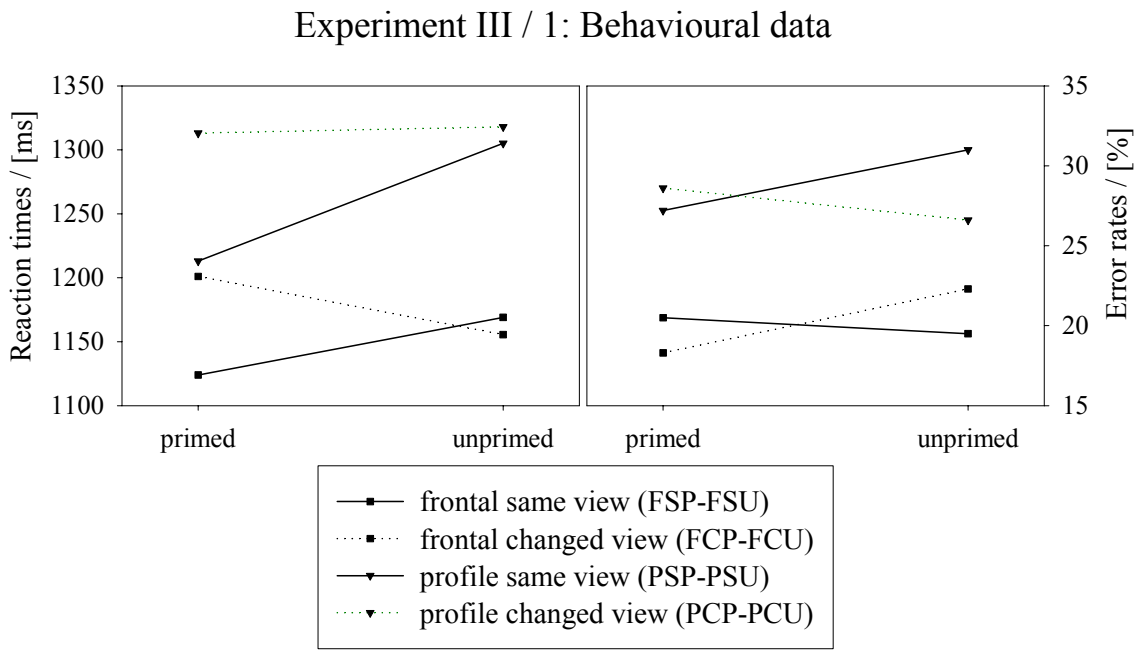


Figure 18: *Experiment III/ 1: Left: Mean RTs and Right: PEs in Experiment III / recognition session 1*

3.1.3.1.1 Reaction times (RTs)

There was a significant main effect of learning view, F (1, 15) = 10.44, $p < .01$, and of view change, F (1, 15) = 8.21, $p < .05$. When primed / unprimed and view-same / view-

changed conditions were collapsed RTs to profile targets, M = 1287.25 ms (SD = 49.78) were generally slower (125 ms on average) compared to frontal targets M = 1162.25 ms (SD = 31.95). There was neither a main effect repetition priming, F (1, 15) = 2.45 nor a threefold interaction learning view x repetition priming x view change, $F < 1$. Repetition priming was affected by view change from prime to target shown by a significant interaction view change by repetition priming, F (1, 15) = 8.49, $p < .01$. For frontal target faces a significant view change by repetition priming interaction, F (1, 15) = 5.38, $p < .05$, reflects speeded RTs (45 ms on average) when the view was the same between prime and target compared to the unprimed condition. But, when the frontal target faces were preceded by their profile view, the repetition priming effect reversed. Participant's reaction in the primed view-changed condition took longer (46 ms on average) compared to the unprimed condition. Pair wise comparisons of repetition priming did not reach significance for both conditions when the view was the same, F (1, 15) = 1.83, and when the view was changed from prime to target, $F < 1$. Comparison of the view-same and the view-changed conditions yielded significant differences for primed targets, F (1, 15) = 8.37, $p < .05$, but did not differ significantly for unprimed targets, $F < 1$. For profile target faces results were somewhat different. There was a trend in the interaction of view change by repetition priming, F (1, 15) = 3.56, $p < .10$. Further comparisons yielded a significant repetition priming effect when the view between prime and target was the same, F (1, 15) = 6.42, $p < .05$. That means participants reacted faster (92 ms) to primed faces when the view of prime and target was the same. There was no effect of repetition priming when the view was changed for profile target faces, $F < 1$. A comparison of the primed same and the primed view-changed conditions revealed a significant difference, F (1, 15) = 10.36, $p < .01$, whereas for unprimed targets no significant differences were found, $F < 1$. When collapsing frontal and profile targets repetition priming was significant when the view of prime and target was the same, F (1, 15) = 3.56, $p < .05$. Pair wise comparisons of RTs of frontal and profile targets in primed and unprimed view-same conditions revealed a significant difference between unprimed frontal and unprimed profile targets only, F (1, 15) = 6.43, $p < .05$. For the view-changed conditions differences between frontal and profile targets were significant in primed and unprimed conditions, Fs (1, 15) = 9.15 and 9.41, ps < .05. Pair wise comparison between

profile primed by the same view and frontal primed by the changed view did not reach significance, $F < 1$.

Table 17: *Experiment III/1: Mean RTs and PEs in Experiment III / Recognition session 1*

Type of target and prime	Mean RT (SD) ms	PE (SD)
Same view / Frontal target		
Identical prime (FSP)	1124 (326)	21 (9)
Unprimed (FSU)	1169 (305)	19 (9)
Priming effect	45	-2
Same view / Profile Target		
Identical prime (PSP)	1213 (267)	27 (8)
Unprimed (PSU)	1305 (284)	31 (11)
Priming effect	92	4
Changed view / Frontal Target		
Identical prime (FCP)	1201 (334)	18 (8)
Unprimed (FCU)	1155 (336)	22 (10)
Priming effect	-46	4
Changed view / Profile Target		
Identical prime (PCP)	1313 (271)	29 (9)
Unprimed (PCU)	1318 (287)	27 (9)
Priming effect	5	-2

FSP / PSP = frontal same view / profile same view primed; FCP / PCP = frontal changed view / profile changed view primed; FSU / PSU = frontal same view / profile same view unprimed; FCU / PCU = frontal changed view / profile changed view unprimed

3.1.3.1.2 Percentage of errors (PEs)

There was a highly significant main effect for the learning view, F (1, 15) = 10.96, p = .01 as on average PEs to profile targets, M = 28.50 % (SD = 1.91) were higher compared to PEs for frontal targets, M = 20.00 % (SD = 1.83). There was neither a main effect for view change, $F < 1$, nor repetition priming, $F < 1$. Repetition priming was affected by view change and learning view. This threefold interaction, F (1, 15) = 5.47, $p < .05$, reached significance. When frontal target faces were analyzed separately, lower PEs for primed target in the view changed condition reached significance, F (1, 15) = 4.62, p = .48, but

turned out to a trend when Bonferroni corrected. PEs appeared to be higher in the primed conditions, when a frontal target was preceded by the same view (FSU), which did not reach significance, $F < 1$. PEs to profile targets reveal lower PEs in the unprimed condition when a profile face was preceded by the changed view (PCU), which was not significant either, $F > 1$. Further profile target analyses did not yield any significant results.

3.1.3.2 Event related potentials (ERPs)

ERPs to frontal and profile faces are displayed separately in *Figures 20* and *21* (see Appendix H for a closer view). Each figure shows the ERPs per condition for target faces primed by the same or the 90° deviant view or for unprimed target faces. The conditions are indicated by different lines and colour. For reasons of facility of inspection not all 58 electrodes are displayed. Only those electrodes are shown where especially early and late potentials due to face recognition are most prominent. Thus the following electrodes were omitted: AF3, AF4, AF7, AF8, C1, C2, C3, C4, C5, C6, CPz, F3, F4, F5, F6, F7, F8, F9, F10, FC3, FC4, FCz, FPz, FT7, FT8, Oz, P7 and P8. For a detailed description of the ANOVA results see 3.1.3.2.3 and *Table 20*. An effect of learning view was seen from 220 to 300 ms and again from 320 to 700 ms and gained strength towards the end of the recording epoch. The differences concerning learning view in amplitude and latency are particularly visible at PO10 and illustrated in *Figure 19*. The effect of view change began in time segment 140-220 ms, reached its maximum at 300-320 ms and disappeared at 500ms. It reached significance again in the last time segment from 600-700 ms. A main effect of repetition priming was seen from 340 to 380 ms. The threefold interaction learning view by repetition priming by view change, was significant from 260 to 420 ms showing two maxima at 280-300 ms and at 400-420 ms. Effects are highlighted by calculating difference waves between the second and the first presentation (primed minus unprimed), shown in *Figure 22* for profile and frontal target faces altogether. In this figure, electrodes where early and late modulation of repetition was most prominent are displayed.

3.1.3.2.1 P100

P100 for target faces was quantified with mean amplitude measures in the time segment 80 to 120 ms. Analysis of mean amplitude in this time segment yielded no effects. Peak amplitude and latency as time of positive maximum at O1 and O2 electrode was measured from 60 to 120 ms. Results are described in *Table 18*. ANOVAs of peak latency and peak-

amplitude yielded significant results only at O1. Analysis of latencies at O1 yielded a main effect learning view, F (1, 15) = 8.31, $p < .05$. The mean peak latency for frontal face was M = 98.87 ms (SD = 2.55) and for profile faces M = 104.06 ms (SD = 1.62). Analysis of the peak amplitude at O1 also yielded a main effect learning view, F (1, 15) = 5.19, $p < .05$, reflecting the difference in amplitudes to profile faces M = 4.89 μV (SD = .53) and frontal faces M = 4.28 μV (SD = .64).

Table 18: *Experiment III/1: Mean peak latency (L in ms) and amplitude (A in μV) for P100*

	P100			
Condition	O1		O2	
	L (SD)	A(SD)	L(SD)	A(SD)
FSP	99 (13.0)	4.3 (2.9)	101 (11.0)	5.7 (4.0)
FSU	100 (13.9)	4.2 (2.2)	100 (14.1)	5.8 (3.8)
FCP	100 (13.8)	4.5 (3.3)	103 (9.1)	6.0 (4.0)
FCU	96 (15.3)	4.2 (2.7)	99 (11.0)	5.8 (4.1)
PSP	104 (7.3)	4.8 (2.5)	101 (7.5)	5.7 (3.5)
PSU	103 (9.9)	5.4 (2.4)	103 (7.7)	6.3 (3.9)
PCP	105 (8.6)	5.1 (2.3)	102 (8.6)	6.0 (3.7)
PCU	103 (7.9)	4.4 (2.0)	102 (9.8)	5.8 (3.7)

FSP / PSP = frontal same view / profile same view primed; FCP / PCP = frontal changed view / profile changed view primed; FSU / PSU = frontal same view / profile same view unprimed; FCU / PCU = frontal changed view / profile changed view unprimed

Inspection of peak amplitudes, as outlined below, suggest a right hemispheric lateralization. The difference between the left and the right hemisphere was assessed by performing ANOVAS, including the factor hemisphere and excluding midline electrodes on the mean amplitude measures in time segment 80-120 ms. This revealed a main effect hemisphere, F (24, 360) = 8.60, $p < .001$, and an interaction hemisphere by view change, F (24, 360) = 2.27, $p < .05$, reflecting a right hemispheric preponderance that was slightly more pronounced when the view was changed, compared to the view same condition.

3.1.3.2.2 N170

N 170 component was measured as mean amplitude between 140 to 220 ms. ANOVA of mean amplitudes revealed a main effect of learning view only as a trend, F (57, 855) =

1.79, $p < .10$, and a main effect of view change, F (57, 855) = 2.10, $p < .05$. There was neither a main effect for repetition priming nor a significant two- or threefold interaction. ANOVAS on the mean amplitude measures yielded neither a main effect hemisphere, $F < 1$, nor any interactions with learning view, repetition priming or view change, $F < 2.01$. Peak amplitude and latency was determined in this time segment (140-220 ms) as maximum negative voltage at PO9 and PO10. Results are described in *Table19*.

Table 19: *ExperimentIII/1: Mean peak latency (L in ms) and amplitude (A in µV) for N170*

	N170			
Condition	PO9		PO10	
	L (SD)	A(SD)	L(SD)	A(SD)
FSP	154 (8.9)	-5.6 (4.1)	158 (11.7)	-5.7 (4.4)
FSU	155 (9.5)	-6.1 (4.8)	155 (8.9)	-6.4 (5.2)
FCP	156 (9.1)	-6.4 (4.7)	158 (11.7)	-6.7 (4.4)
FCU	158 (8.9)	-5.7 (4.5)	160 (10.1)	-6.4 (4.1)
PSP	166 (9.8)	-6.0 (4.2)	165 (10.2)	-7.0 (3.5)
PSU	168 (9.9)	-5.2 (3.8)	166 (9.0)	-6.0 (3.6)
PCP	172 (9.3)	-6.1 (3.9)	169 (8.4)	-7.0 (3.5)
PCU	172 (10.2)	-6.9 (3.3)	169 (9.9)	-7.5 (3.2)

FSP / PSP = frontal same view / profile same view primed; FCP / PCP = frontal changed view / profile changed view primed; FSU / PSU = frontal same view / profile same view unprimed; FCU / PCU = frontal changed view / profile changed view unprimed

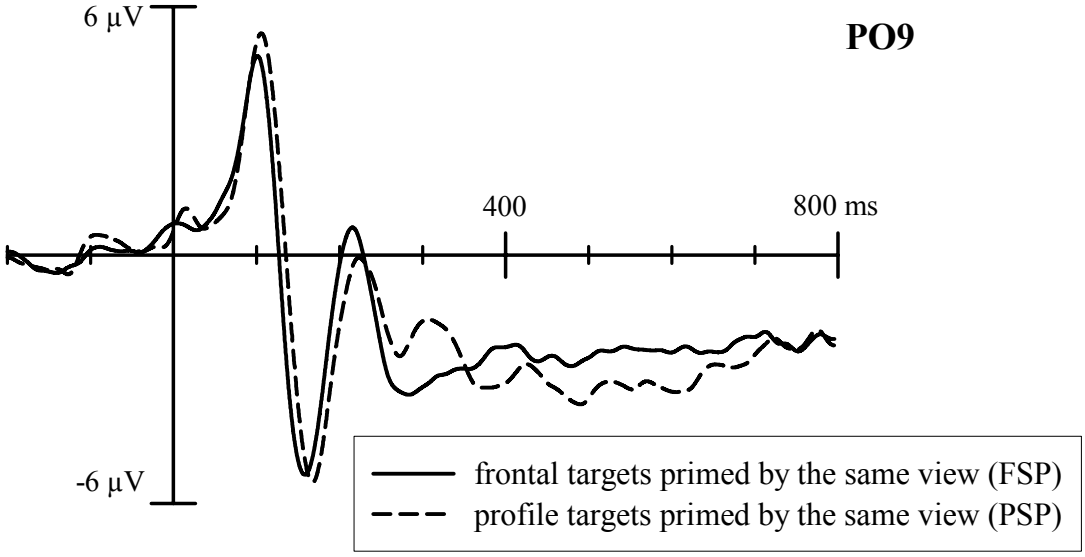


Figure 19: Experiment III/1: N170 to frontal and profile targets primed by the same view

Analysis of peak latencies at PO9 and PO10 yielded a main effect of learning view, *Fs* (1, 15) = 39.77 and 39.31, $p < .001$, and view change, *F*s (1, 15) = 66.05 and 7.71, *p*s < .001 and .05. This is reflected by a delay of 15 ms from frontal to profile target faces (*Figure 19*). Mean peak latency to frontal target faces was $M = 155.93$ ms ($SD = 2.00$) and to profile target faces was $M = 169.68$ ms ($SD = 2.35$). The main effect of view change reflected a small delay from only 3 ms on average for targets preceded by the changed.as compared to the same view. Peak amplitudes at PO9 and PO10 yielded a significant main effect of view change, *F*s (1, 15) = 5.76 and 7.12, *p*s < .05 and 001 as well. Amplitudes in the view-changed condition turned out to be somewhat larger compared to the view same condition. Moreover, a significant threefold interaction of learning view by repetition priming by view change, *F*s (1, 15) = 6.36 and 8.95, *p*s < .05 and .01, was found in peak amplitudes. Pair wise comparisons for peak amplitudes at PO9 / PO10 revealed a significant effect of view change for profile targets only in the unprimed condition, *F*s (1, 15) = 5.99 and 5.67, *p*s < .01. Even though peak amplitudes (as listed in *Table19)* show larger peaks for profile targets, there was no main effect learning view, $F < 1$.

3.1.3.2.3 Repetition priming effects

To analyse repetition priming effects mean amplitude measures were quantified in 14 adjacent 20 ms - time segments from 220 ms to 500 ms, from 500-550, 550-600, 600-700

and 700 to 800 ms. This fine grained 20 ms-quantification was chosen as larger time segments, like 40 ms as chosen in Experiment I and II, did not yield significant results with respect to repetition priming when pair wise comparisons were calculated. *Table 20* contains the Bonferroni-corrected results of the ANOVAS that were performed per time segment. *Figures 20* and *21* show differences in ERPs to primed and unprimed targets. To facilitate the inspection ERPs for the frontal and profile targets are presented separately. An overall ANOVA yielded highly significant effects of learning view from 220 to 280 ms, and from 320 ms until the end of the recording epoch. It reached a maximum from 360 to 400 ms. From 280-300 and 300-320 ms there was no main effect of learning view, *F*s < 1. Within these time windows the effect of view change was strongest and diminished thereafter, but was significant until 500 ms. A main effect of repetition priming turned out to be only significant in the time segments 340-360 ms and from 360-380 ms. There was a significant threefold interaction learning view by repetition priming by view change from 260 to 420 ms, which was strongest from 280 to 320 ms and again from 400-420 ms. Frontal target faces primed by their same view and their profile view as well profile target faces primed by the same view elicited an increased positivity or decreased negativity at the vertex, which was maximal around 350 ms. For frontal target faces primed by the same view this lasted until 450 ms, for profile targets primed by the same view until 400 ms and for frontal targets primed by their profile view until the end of the recording epoch. This is particularly visible at Cz (*Figure 22*). At prefrontal sites (FP1, FP2) there was a decrease of positivity for frontal and profile faces that had been primed by the same view. When view was changed, with respect to frontal targets a slight increase of positivity appeared comparable to the effect at the vertex.

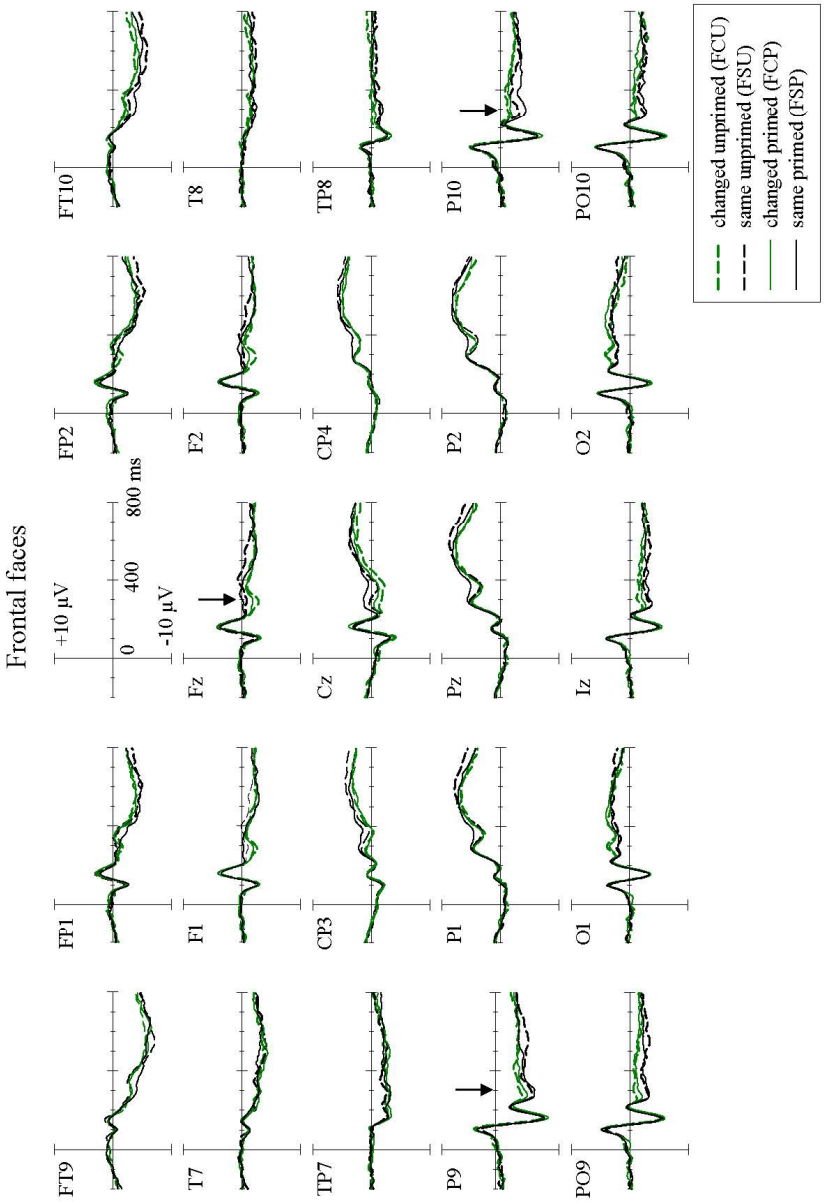


Figure 20: *Experiment III/1: ERPs for frontal targets preceded by the same or the changed view in primed and unprimed conditions (see also Appendix H)*

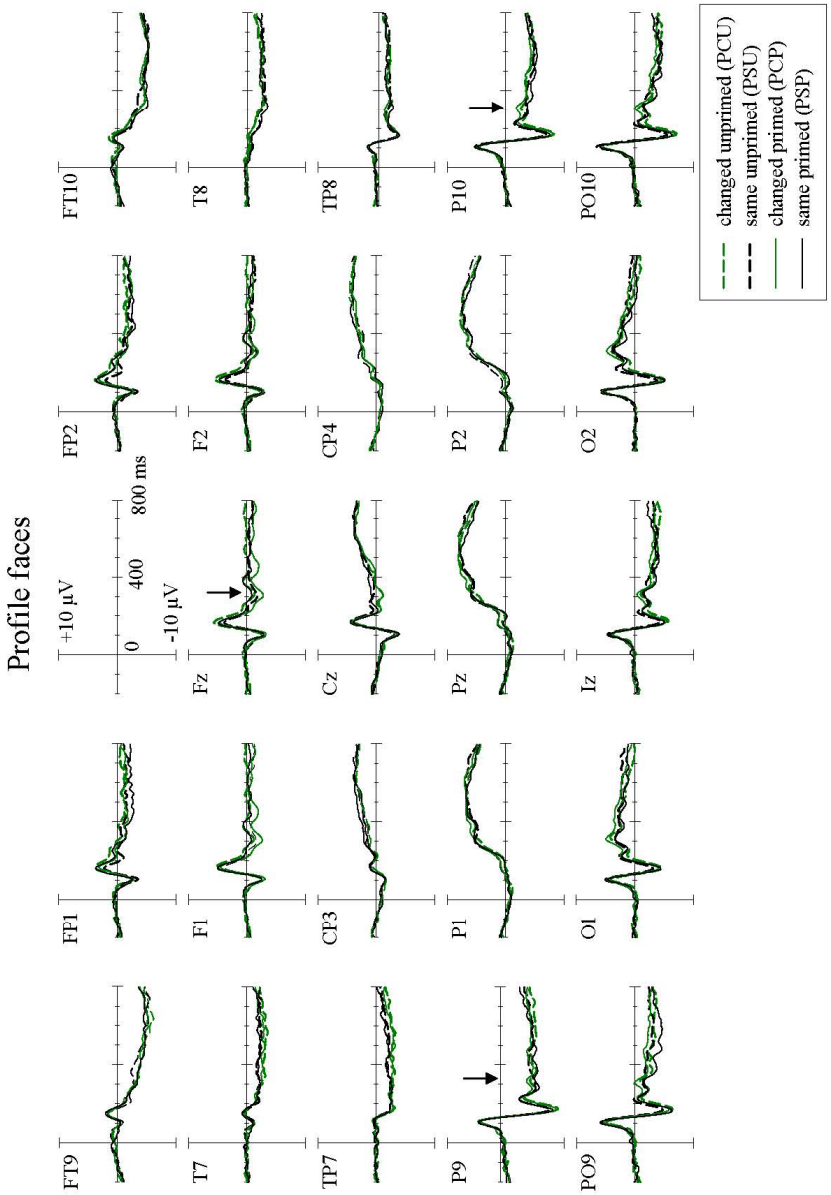


Figure 21: *Experiment III/1:* ERPs for profile targets preceded by the same or the changed view in primed and unprimed conditions *(see also Appendix H)*

Table 20: *Experiment III / 1: Results of the ANOVAs for amplitude measures of the repetition ERP components*

		Time segments (ms)												
Source	df	80-120	140-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360	360-380	380-400	400-420	420-440	440-460
All conditions:															
Learning view	57, 855		1.79(*)	7.52***	5.84***	3.98**		2.34(*)	4.95**	7.00**	8.83***	8.12***	5.79***	5.77***	
Repetition	57, 855									2.62**	3.15**	2.60(*)	2.24(*)		
View change	57, 855		2.10**	3.65**	2.75*	4.42**	6.66***	7.38**	5-10**	2.62**	3.02**	2.99**	3.55**	3.81**	
Learning view x Repetition x View change	57, 855			2.27(*)	2.04(*)	2.69*	2.89**	2.72*	2.32*	2.47*	2.92**	2.61**	3.00**	1.82(*)	
Frontal targets:															
Repetition	57, 855					1.83(*)	2.58**	2.24*	1.78(*)	2.10(*)	2.44*	2.33*			
View change	57, 855					6.79***	8.51***	7.57***	5.98***	4.41**	4.20**	3.64**	3.96**	4.57***	4.04**
View change x Repetition	57, 855								2.52*	2.28*			2.30*		
Repetition - same view : FSP – FSU	57, 855								2.48(*)	3.14*	2.78(*)	2.77(*)	.		
η_p^2									.14	.17	.16	.16			
Repetition - changed view: FCP- FCU	57, 855						.	1.95(*)							
η_p^2								.12							
Profile targets:															
Repetition	57, 855														
View change	57, 855						2.31*	3.16*							
View change x Repetition						3.49**	3.86**	2.35*			2.62*	2.05(*)			
Repetition - same view: PSP - PSU	57, 855										.	.			
Repetition - changed view: PCP- PCU	57, 855														

(*) $p < .10$ (Trend); *$p < .05$, **$p < .01$; ***$p < .001$; Bonferroni-corrected α - level for pairwise comparisons; not significant (n.s.) F-values not listed; η_p^2 = explained variance (effect size); FSP/ PSP- frontal / profile same primed; FSU/ PSU- frontal / profile same unprimed; FCP/ PCP- frontal / profile changed primed; FCU/ PCU- frontal / profile changed unprimed

Differences in ERPs as described for frontal targets were not found for profile targets primed by their frontal view, either at the central electrodes or at the prefrontal electrodes, beside a positivity for primed targets at parieto-central electrodes such as Pz. ANOVA to frontal target faces revealed an effect of repetition priming from 280 to 320 ms and from 360 to 400 ms, which corresponds to the ERE and the LRE. From 320 to 360 ms the repetition priming effect was only a trend. The effect of view change was highly significant from 260 to 500 ms but strongest from 260 to 340 ms, which corresponds to the ERE. The interaction repetition by view change was significant from 320 to 360 ms and from 400-420 ms, which reflects that there was no repetition priming effect for faces where the view was changed from the first to the second encounter in these time segments. For profile targets ANOVA revealed an effect of view change from 280 to 320 ms. From 260 to 320 and 360 to 400 ms the interaction of repetition by view change was significant. As is outlined in the following, the ERE and the LRE could be qualified by pair wise comparisons between primed and unprimed targets for the view-same and the view-changed condition only as a trend and validated by one-tailed t-tests concerning their GFP.

3.1.3.2.3.1 ERE

Repetition of frontal target faces with the same or the profile view caused an ERE which is particularly visible as fronto-central positivity. This temporally limited modulation appeared around 250 to 350 ms and reversed polarity at temporal and parieto-occipital sites and is most evident at TP7/TP8, P9/P10, PO9/PO10. The effect for faces preceded by their profile view was somewhat smaller when visually inspected. Pair wise comparisons revealed a repetition priming effect for frontal faces primed by the same view from 320 to 340 ms that diminished to trend after Bonferroni correction. When frontal target faces were preceded by the profile view the repetition priming effect was found in segment 300-320 ms, but after Bonferroni correction was reduced to a trend. For that reason the results were validated by one-tailed t-tests performed for pair wise comparisons of the global field power (GFP, Lehmann & Skrandies, 1980, 1984) for the primed and unprimed conditions in these time segments where the effects had been found (see 3.1.2.6). For frontal faces primed by the same view the repetition priming effect could be validated by a significant GFP difference between primed and unprimed condition, t (15) = 2.03, $p < .05$, in time segment 320-340. In time segment 300-320 ms this analysis revealed a significant priming effect for frontal faces primed by their profile view, t (15) = - 1.93, $p < .05$. The difference

in overall activity across the scalp between primed and unprimed targets validates the trend, as described above, for a repetition priming effect that was found in the ANOVA in that time segment. Thus, from 320-340 ms a repetition priming effect was found that corresponds to the ERE for the repetition priming condition where the view was the same for prime and target. From 300-320 ms a repetition priming effect was found that corresponds to the ERE for primed targets where the view was changed from prime to target.

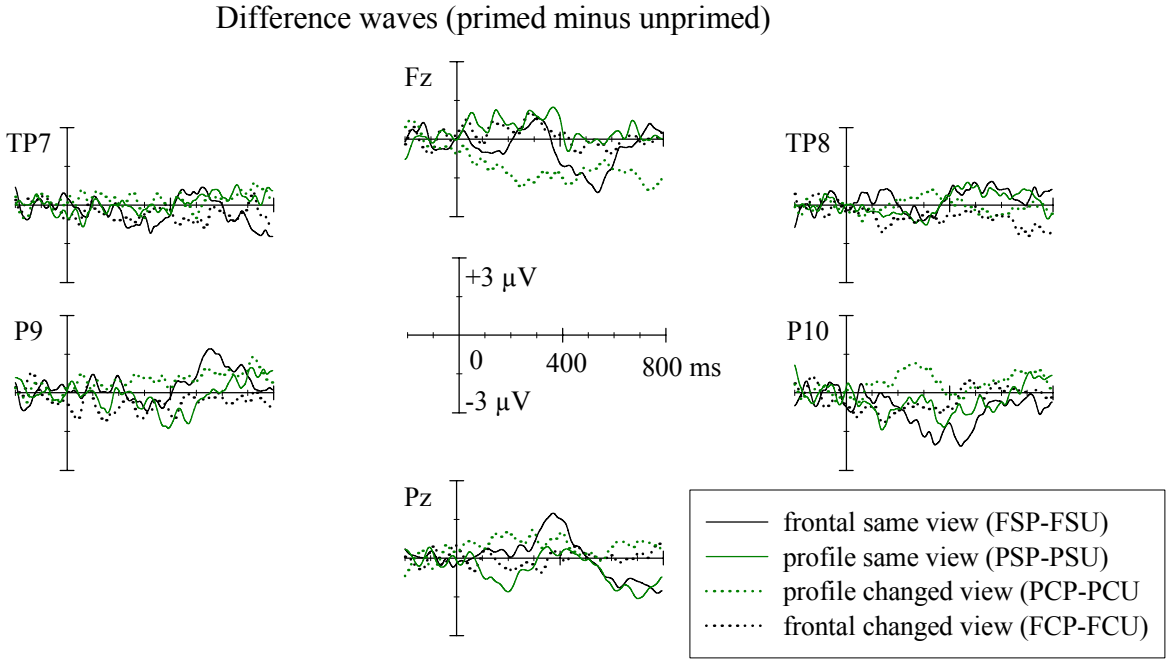


Figure 22: *Experiment III/1: Difference waves (primed minus unprimed) for frontal and profile targets preceded by the same or the changed view*

Finally, the GFP differences for primed and unprimed targets where compared with respect to the view-changed and the view-same condition, which reached significance t (15) = 2.64, $p < .05$. Thus, the difference of the GFP is smaller in the view change condition compared to the view same condition. Still, it remains that the repetition priming effects concerning both the view-same and the view-changed conditions were not very strong, as reflected by small effect sizes of 14% for the view-same condition and 12 % for the view-changed condition (explained variances by partial eta square - η_p^2). Repetition of profile target faces affected an earlier transient component characterised by the typical ERE modulation with an increased positivity to primed faces at fronto-central electrodes and reversed polarity at temporal and parieto-occipital sites and is most evident

at TP7/TP8, P9/P10, PO9/PO10. With reference to the Fz electrode this temporally limited modulation appeared around 250 to 400 ms. The ERE modulation was detectable only for profile targets primed by the same view. It failed to reach significance when primed and unprimed conditions were pair wise compared in the time segments from 260 to 320 ms where the interaction of view change by repetition priming was significant for profile target faces. Likewise, pair wise comparisons of the GFP according to primed and unprimed targets did not yield significant overall ERP differences, *t*s < 1. When view was changed from prime to target ERPs are more positive for unprimed compared to the primed condition. This was most pronounced at Fz and Pz and reversed polarity at temporal and parieto-occipital sites and lasted throughout the recording epoch. This suggests that there is no ERE modulation for profile targets preceded by the corresponding frontal view. Pair wise comparisons for the view-changed condition failed to reach significance. Comparison of the GFP for primed and unprimed targets in the view change condition revealed significant differences in overall ERP activity in time segment 300-320 ms, $t\ (15) = 2.45$, $p < .05$.

Hemispheric differences in repetition effects to frontal target faces:

To test hemispheric differences of the found EREs the same technique was used as in Experiment I and II. This revealed a significant effect of hemisphere for frontal target faces in the view-same condition, $F\ (24, 360) = 28.39$, $p < .001$, and went on until 400 ms, *F*s (24, 360) = 24.43, 21.90 and 23.01, *p*s = .001. The same analysis for frontal faces preceded by the corresponding profile view in time segment 300-320 ms revealed again a significant effect hemisphere, $F\ (24, 360) = 22.45$, $p < .001$. Results reflect that the ERE is more pronounced in the right hemisphere independently from repetition with the same or a changed view, as is reflected by peak analyses (*Table 21*).

ERE – Peaks and Latencies:

Despite of the high level of noise a peak detection for the ERE was performed to give a description about the size of its amplitude of the repetition priming effect. Peak was determined in the time window from 250 to 350 ms as a maximum at Fz and minima at P9/P10, where the ERE was most pronounced.

Table 21: Experiment III/1: *Mean peak latency (in ms) and amplitude (in µV) for the ERE*

	ERE					
	Fz		P9		P10	
	L(SD)	A(SD)	L(SD)	A(SD)	L(SD)	A(SD)
FSP - FSU	327 (29.1)	1.7 (1.8)	319 (27.9)	-1.7 (2.3)	338 (19.6)	-2.9 (2.2)
FCP - FCU	338 (31.8)	1.2 (1.7)	317 (24.2)	-1.4 (2.7)	329 (26.8)	-1.5 (1.3)
PSP - PSU	329 (27.3)	1.7 (1.8)	338 (35.1)	-1.7 (2.0)	336 (27.1)	-1.6 (1.7)
PCP - PCU	332 (23.8)	0.6 (2.8)	328 (20.3)	-0.2 (2.4)	326 (25.0)	-0.2 (3.2)

FSP / PSP = frontal same view / profile same view primed; FCP / PCP = frontal changed view / profile changed view primed; FSU / PSU = frontal same view / profile same view unprimed; FCU / PCU = frontal changed view / profile changed view unprimed

The results are compiled by *Table 20*. Results show a repetition priming effect for frontal targets primed by their same view, most salient at P10 and Fz, ranging from 1.7 µV to –2.9 µv. When view was changed the repetition priming effect is nearly half the size compared to the view-same condition, but still present as ranging from 1.2 µV to –1.5 µV. Even though the found EREs for the view-same and the view-changed conditions reached significance in two different, but consecutive time segments (*Table 20*), an effect of peak latency or peak amplitude was not found between these two conditions, neither at Fz, nor at P9/P10, *F*s < 2. When profile target faces are primed by the same view a peak was found located in time segment 320-340, still not being qualified by a significant result in the accordant time segment. When view was changed during repetition of profile target faces no repetition effect was found as reflected by amplitudes around the baseline.

3.1.3.2.3.2 LRE

For frontal target faces the ERE was followed by a parieto-central positivity and a prefrontal negativity that appeared from 340 to 400 ms and corresponds to the LRE. This component was detectable for faces primed only by the same view. There was no such component in the condition where the view had changed from the first to the second encounter. This is illustrated in the difference waves at Pz (*Figure 22*). ANOVA results revealed a repetition priming effect that was strongest in time segment 340-360 ms (explained variance 17%) and diminished thereafter to a trend after Bonferroni correction from 360 to 400 ms (explained variance 16%). The results were validated by one-tailed t-

tests performed for pair wise comparisons of the GFP for the primed and unprimed conditions. Significant overall ERP differences between primed and unprimed targets in the view-same condition in time segments 360-380 and 380-400 ms, *t*s (15) = 2.23 and 2.15, *p*s < .05, were found and validated the LRE in these time segments. For profile targets parieto-central positivity corresponding to the LRE was detectable for profile target faces only in the view-same condition to be seen as a minimal modulation at Pz (*Figure 22*). But, from 360-380 ms post-hoc comparisons of the significant view change by repetition interaction failed to reveal significant differences between primed and unprimed targets, $F < 2.30$. Also analyses of differences of GFP did not yield significant results in this time segment, $t < .05$. An LRE for profile targets was not found.

3.1.3.2.3.3 Topographic analysis

Topographies are compiled in *Figure 23* and show the amplitudes of difference waves (primed minus unprimed). Topographical analyses of the time segments that correspond to the ERE and the LRE were performed with scaled amplitudes of difference waves. (As being validated by significant differences concerning the overall ERP activity reflected by GFP.) For frontal targets primed by the same view topographies over time segments 320-340 ms as corresponding to the ERE compared to topographies of the consecutive time segments from 320-340, 340-360, 360-380 and 380-400ms revealed a qualitative difference from 320-340 to 380-400 ms as a trend, F (57, 855) = 1.93, $p = .06$. Beside that consecutive time segments were topographically indistinguishable, Fs<1. Thus, the ERE can be related to the time segment 320-340 ms and the LRE to the time segment 380-400 ms.

Analyses of the topography of the ERE for the view-changed condition (a profile face preceded the frontal target) as found in time segment 300-320 ms revealed the following: When compared to the ERE as found in the view-same condition (320-340 ms) it is clear that the ERE after view change is smaller in size and seems to be qualitatively different because negativity is more temporo-parietal pronounced and positivity more frontally directed. Still, a pair wise comparison based on scaled data by mean vector length (McCarthy & Wood, 1985; 2.1.2.6) did not reveal a significant difference, F<1. This scaling method disregards individual differences or within-group variability, since the mean score of the electrode sites is scaled, real topographical differences might be eliminated (Haig, Gordon & Hook, 1997). Therefore, differences between the ERE for the

view-same condition and the ERE for the view-changed condition were analyzed again by scaling difference waveforms in the corresponding time segment for each participant to the same overall amplitude within these conditions, with the average distance of the mean, that was derived from the individual mean ERPs, as divisor (Herzmann & Sommer, 2007). Pair wise comparison, even based on the individual scaling method, did not yield a significant difference , F (57, 855) = 1.19.

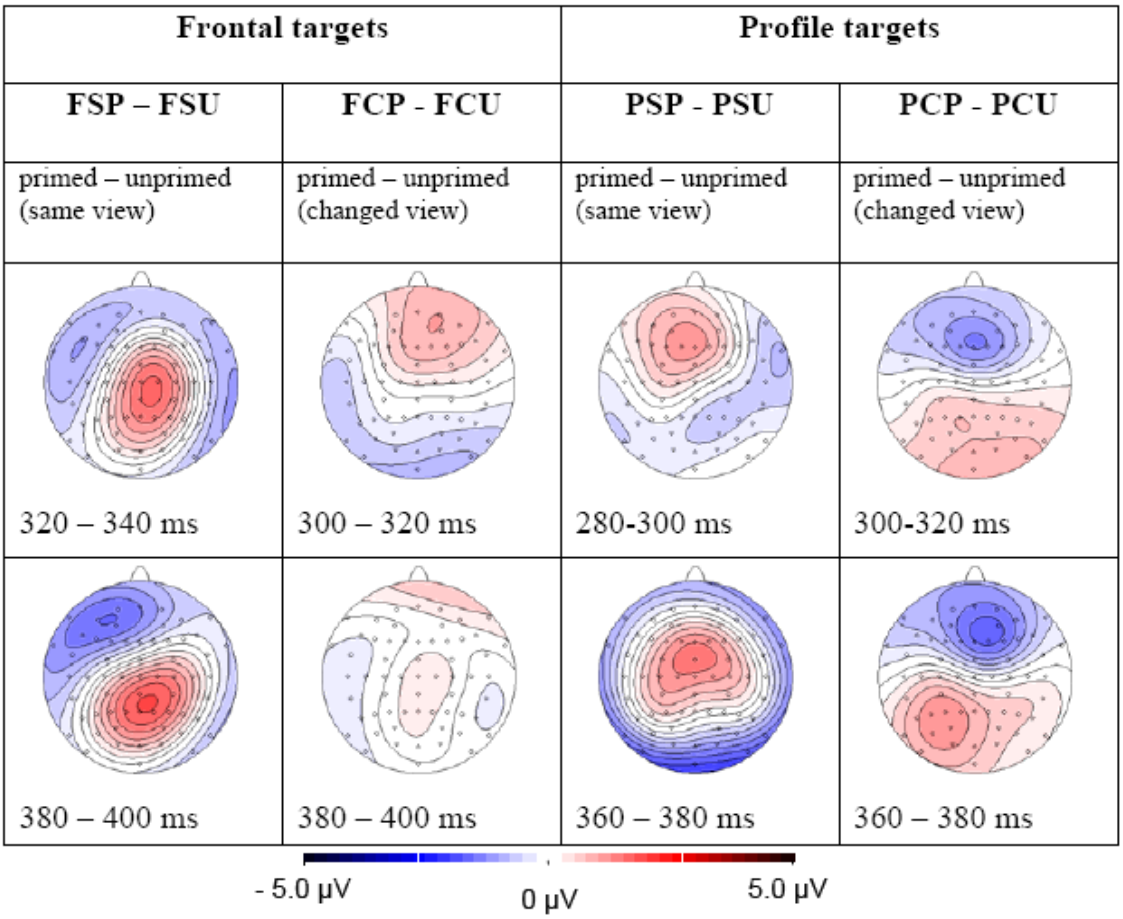


Figure 23: *Experiment III/1: Voltage maps of ERP difference waves between primed and unprimed conditions corresponding to the ERE and LRE time segments. Spherical spline interpolation was used. Equipotential lines are separated by .25 µV.*

Topographies for profile target faces in the view-same condition are displayed (*Figure 23*) for time segments 280-300 ms and from 360-380 ms, according to the time segments where ANOVA of the unscaled amplitudes yielded a significant interaction of view change by repetition. For profile targets preceded by the same view the topographies from 260 to 400 ms do show modulations that rather resemble an ERE for both the earlier and the later

time segment, illustrating an inferior-temporal negativity and a fronto-central positivity. There was no LRE modulation for profile targets when consecutive time segments where inspected. When view was changed for profile targets topographies showed an atypical picture that neither reconciles the ERE nor the LRE as they present topographies characterised by a posterior positivity and a fronto-central negativity for both of the displayed time segments. Here the time segment 300-320 ms is displayed because of the significant *t*-Test concerning GFP power between primed and unprimed targets (see 3.1.3.2.3.1).

3.1.4 Results of Recognition session 2: Familiar specificity of the ERE

3.1.4.1 Behavioural Data

PEs and RTs to target faces are summarized in *Table 22* and *Figure 24*. An inspection of these data shows that error rates did not vary with repetition priming conditions.

3.1.4.1.1 Reaction times (RTs)

Overall ANOVA results yielded a main effect learning view, F (1, 7) = 43.71, $p < .001$. RTs to frontal faces, M = 681.81 ms (SD = 27.02), were 74 ms faster compared to profile faces, M = 755.42 ms (SD = 20.98). The interactions of learning view by repetition priming, learning view by familiarity or the threefold interaction learning view by familiarity by repetition priming failed to reach significance. The main effects familiarity, F (1, 7) = 8.91, $p < .05$, and repetition priming, F (1, 7) = 24.27, $p < .01$ as well as the interaction of both, familiarity by repetition priming F (1, 7) = 12.83, $p < .01$ was significant, reflecting that there was only a repetition priming effect for familiar faces. There was no repetition priming effect for unfamiliar frontal or profile faces, Fs < 1. For faces that were learned from the frontal view there was a highly significant repetition priming effect, F (1, 15) = 34.95, $p < .001$, as well as for faces learned from the profile view, F (1, 7) = 16.41, $p < .01$. Repetition priming for frontal targets was somewhat larger compared to profile targets, F (1, 7) = 34.94, $p < .001$.

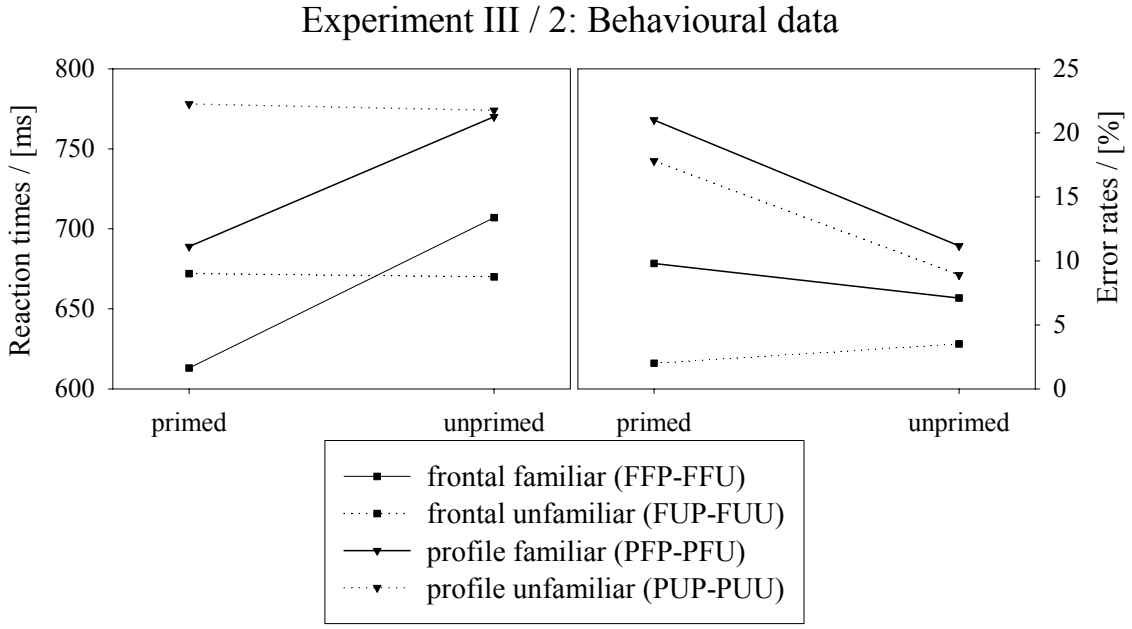


Figure 24: *Experiment III / 2: Left: Mean RTs and Right: PEs in*

Post-hoc comparisons of familiar and unfamiliar targets in the unprimed condition reached significance for frontal targets, F (1, 15) = 7.73, $p < .01$, but not for profile targets, $F < 1$. For the primed conditions RT difference yielded significance for frontal, F (1, 15) = 23.47, $p < .001$, and profile targets, F (1, 7) = 26.99, $p < .01$.

3.1.4.1.2 Percentage of errors (PEs)

Overall ANOVA results yielded a main effect learning view, F (1, 7) = 49.97, $p < .001$. PEs to frontal faces, M = 5.69 % (SD = 1.10), were 9 % lower compared to PEs to profile faces, M = 14.73 % (SD = 9.89). There was a trend to a significant interaction learning view by repetition priming, F (1, 7) = 5.26, $p < .10$. Neither the interaction learning view by familiarity nor the threefold interaction learning view by familiarity by repetition priming reached significance. Further analyses where calculated separately per learning view. For frontal targets results yielded a main effect of familiarity F (1, 15) = 15.39, $p < .001$, and an interaction of familiarity by repetition priming, F (1, 15) = 22.88, $p < .01$, but no main effect repetition priming, $F < 1$. PEs were always somewhat lower for unfamiliar targets in the primed (8%) and unprimed condition (3%), reflecting a bias to “unfamiliar” responses for frontal targets. Post-hoc comparisons for familiar and unfamiliar targets yielded significance for primed, F (1, 15) = 17.28, $p < .01$, and unprimed targets, F (1, 15) = 6.67, $p < .05$. For profile targets, besides a main effect of repetition priming, F (1, 7) =

22.88, $p < .01$, there was no significant main effect of familiarity or an interaction familiarity by repetition priming, $F < 1$. PEs were significantly lower in the unprimed condition for both familiar, $F(1, 7) = 14.35$, $p < .01$, and unfamiliar faces, $F(1, 7) = 8.33$, $p < .05$. Thus, when compared to the variation in RTs with priming and familiarity there is a speed-accuracy trade-off at least when a familiarity decision to profile target faces was required.

Table 22: *Experiment III/2: Mean RTs and PEs*

Type of target and prime	Mean RT (SD) ms	PE (SD)
Familiar targets: Frontal		
Identical prime (FFP)	613 (104)	10 (8)
Unprimed (FFU)	707 (96)	7 (7)
Priming effect	94	- 3
Familiar targets: Profile		
Identical prime (PFP)	689 (75)	21 (8)
Unprimed (PFU)	770 (62)	11 (16)
Priming effect	81	-10
Unfamiliar targets: Frontal		
Identical prime (FUP)	672 (99)	2 (3)
Unprimed (FUU)	670 (89)	4 (3)
Priming effect	-2	2
Unfamiliar targets: Profile		
Identical prime (PUP)	778 (61)	18 (13)
Unprimed (PUU)	784 (69)	9 (6)
Priming effect	6	-9

FFP / PFP - frontal / profile familiar primed; FFU / PFU - frontal / profile familiar unprimed; FUP / PUP- frontal / profile unfamiliar primed; FUU / PUU-.frontal / profile unfamiliar unprimed

3.1.4.2 Event related potentials (ERPs)

ERPs to frontal and profile target faces are displayed separately on selected electrode sites in *Figure 25* and *26*. Each figure shows the ERPs for familiar and unfamiliar targets in the primed and unprimed conditions. The conditions are indicated by different lines and colour. Electrode sites, time period and baseline are presented according to recognition session 1 of Experiment III. Please note, that only eight participants where involved in the familiarity decision to profile targets. For a detailed description of the ANOVA results see *Table 25*. Overall ANOVA revealed an effect of learning view which was significant from 140 to 220 ms, from 260 to 340 ms and again from 480 to 800 ms. The effect of familiarity began in time segment 300-320 ms, lasted until time segment 500-550 ms and was strongest from 420 to 460 ms. The interaction of familiarity by repetition priming was significant from 280 ms onwards, but strongest in time segments 320 to 360 ms and diminished into a trend after 400 ms, lasting until 480 ms. Repetition priming effects were highlighted by calculating difference waves between the second and the first presentation (primed minus unprimed). *Figure 27* shows difference waves for frontal and profile target faces per familiarity. As before electrode sites most representative for the ERE and the LRE are displayed.

3.1.4.2.1 P100

P100 was quantified with mean amplitude measures in the time segment 80-120 ms. Analysis of mean amplitude in this time segment yielded no effects. Peak amplitude and latency as time of positive maximum at O1 and O2, were determined from 80 to 120 ms. Results are described in *Table 23*. ANOVAS of peak latency and amplitude did not yield any significant results. Thus P100 was found to be independent of learning view and familiarity at M = 100.25 ms (SD = 2.88) with a mean amplitude of M = 5.53 µV (SD = 0.69). A comparison of peak amplitudes between O1 and O2 suggest a right hemispheric preponderance. There was no significant main effect hemisphere or an interaction of learning view by hemisphere, Fs < 2.45.

Table 23: *Experiment III/2: Mean peak latency (L in ms) and amplitude (A in µV) for P100*

	P100			
Condition	O1		O2	
	L (SD)	A(SD)	L(SD)	A(SD)
FFP	103 (8.9)	5.1 (2.8)	101 (9.1)	6.3 (3.9)
FFU	100 (11.3)	4.9 (2.8)	99 (11.2)	6.0 (3.8)
FUP	103 (9.4)	4.5 (2.9)	101 (9.5)	5.9 (3.6)
FUU	100 (9.4)	4.5 (3.0)	100 (9.4)	5.6 (3.7)
PFP	105 (8.5)	4.6 (3.4)	96 (16.7)	6.3 (4.2)
PFU	104 (9.8)	5.2 (3.8)	99 (9.6)	6.3 (4.4)
PUP	97 (18.8)	5.6 (3.9)	95 (14.6)	6.4 (4.4)
PUU	98 (18.6)	5.1 (2.8)	103 (9.2)	6.2 (3.2)

FFP / PFP - frontal / profile familiar primed; FFU / PFU - frontal / profile familiar unprimed; FUP / PUP -frontal / profile unfamiliar primed;FUU / PUU - frontal / profile unfamiliar unprimed;

3.1.4.2.2 N170

The N170 component was measured as average voltage between 140 and 220 ms. Within that time segment peak amplitude and latency was determined as time of maximum negative voltage at PO9/PO10. Results are compiled in *Table 24*. ANOVAS of mean amplitudes yielded a significant effect of learning view, *F*s (57, 399) = 2.28, $p < .05$. Otherwise there were neither main effects concerning familiarity or repetition priming nor any significant interactions. Analyses of peak latencies revealed a significant effect of learning view reflecting a 10 ms shift in latency from frontal, $M_{PO9/PO10}$ = 158.63 ms (*SD* = 2.75), to profile target faces, $M_{PO9/PO10}$ = 168.75 ms (*SD* = 2.66), at PO10, F (1, 7) = 17.85, $p < .01$, and PO9, F (1, 7) = 16.94, $p < .01$. Even though at PO10 data suggests larger peaks to profile faces, *M* = -6.80 µV (*SD* = 1.81), compared to frontal target faces, *M* = -5.82 µV (*SD* = 1.80), ANOVAS considering peak amplitudes yielded no significant results, *F*s < 2. Analyses of hemispheric differences did not yield significant results, either as a main effect hemisphere, or as an interaction hemisphere by learning view, *F*s < 1.

Table 24: *Experiment III/2: Mean peak latency (L in ms) and amplitude (A in µV) for N170*

	N170			
Condition	PO9		PO10	
	L (SD)	A(SD)	L(SD)	A(SD)
FFP	161 (8.7)	-5.5 (3.8)	156 (7.9)	-5.3 (4.3)
FFU	157 (8.3)	-5.5 (4.5)	154 (10.3)	-5.1 (4.4)
FUP	156 (7.8)	-5.3 (4.1)	156 (10.2)	-5.7 (4.5)
FUU	158 (11.2)	-5.6 (3.9)	158 (8.8)	-5.8 (4.0)
PFP	165 (7.1)	-5.4 (4.8)	164 (6.0)	-7.2 (4.6)
PFU	172 (14.0)	-5.1 (4.9)	166 (9.5)	-6.7 (5.6)
PUP	169 (13.0)	-5.1 (5.8)	166 (7.1)	-6.5 (5.4)
PUU	168 (11.0)	-5.3 (5.8)	164 (6.8)	-6.7 (5.3)

FFP / PFP - frontal / profile familiar primed; FFU / PFU - frontal / profile familiar unprimed; FUP / PUP -frontal / profile unfamiliar primed;FUU / PUU - frontal / profile unfamiliar unprimed;

3.1.4.2.3 Repetition priming effects

To analyse repetition effects mean amplitude measures were quantified in 14 adjacent 20 ms time segments from 220 to 500 ms, from 500-550, 550-600, 600-700 and 700-800ms. *Table 25* contains the most important ANOVA results (including Bonferroni correction) performed per time segment. *Figure 25* and *26* and the difference waves in *Figure 27* show differences in ERPs to primed and unprimed conditions separated by familiarity and learning view. An overall ANOVA yielded a main effect of learning view from 260 to 340 ms, 480 to 800 ms, being strongest in time segment 550-600 ms and weakest in last time segment 700-800 ms. An effect of familiarity started in time segment 300-320, lasted until 500-550ms, but reached a maximum in time segment 440-460 ms. Repetition priming yielded significant results from 280-300 ms, lasted until 500-550 ms and was strongest from 380-400 ms. The interactions learning view by familiarity or learning view by familiarity by repetition priming never reached significance, Fs < 1. The interaction familiarity by repetition priming reached significance in time segment 280-300, continued until time segment 380-400 ms, diminished into a trend and disappeared thereafter. It reached highest F-values in time segment 320-340 ms. Post-hoc comparisons of familiar

and unfamiliar target faces in the unprimed condition (the old / new effect) did not reach significance (*F*s < 1.15). ANOVA performed separately for familiar target faces yielded a repetition priming effect lasting from 280 to 600 ms. It reached highest *F*-values in time segment 320-340 ms. For familiar target faces this is reflected in an increased positivity or a decreased negativity at the vertex for both frontal and, although smaller in size for profile primed target faces. The increased positivity reached a maximum around 380ms at central electrode sites (Cz). After 400 ms the effect minimized and disappeared around 500ms. At prefrontal sites there was a decrease of positivity for primed frontal and profile target faces. ANOVA performed for unfamiliar target faces yielded smaller sized, but significant repetition priming effects per time segments beginning in time segment 280-300 and disappearing in segment 340-360 ms. In reference to *F*-values it was most pronounced in time segment 320-340. Illustrated by *Figure 26* primed unfamiliar target faces elicited an increased negativity that can be particularly seen at the fronto-central electrodes, and a parietal positivity.

3.1.4.2.3.1 ERE

For familiar targets repetition priming of frontal and profile faces elicited an earlier transient component as a temporally limited increased positivity to primed faces from 250 to 350 ms (*Figure 27*). The modulation reversed polarity at fronto-temporal, temporal and temporo-parietal sites and was most evident at FT9/FT10, TP7/TP8, P9/P10. This early modulation corresponds to the ERE. It reached its maximum around 320 ms for both frontal as well as profile target faces, which corresponds to the interaction of familiarity by repetition priming that reached highest *F*-values in time segment 320-340 ms in the overall ANOVA (*Table 25*). Pair wise comparisons to frontal target faces revealed a significant repetition priming effect from 280 to 550 ms, with a highest effect size by 39% in time segment 380-400 ms. The repetition priming effect to frontal targets in time segments 280 to 340 was related to the ERE because of the ERE typical modulation in these time segments. Pair wise comparisons for profile targets revealed a repetition priming effect from 300 to 600 ms, somewhat time-shifted as compared to frontal targets. The early component started at 300-320 ms and reached its maximum in time segment 320-340 ms. A comparison of the EREs for frontal and profile familiar targets in time segment 320-340 revealed an even higher effect size by means of explained variances for profile target faces (43%) relative to frontal target faces (31%). Still, pair wise comparisons of significant

repetition priming effects between profile and frontal target faces did not yield significant differences, Fs < 1.

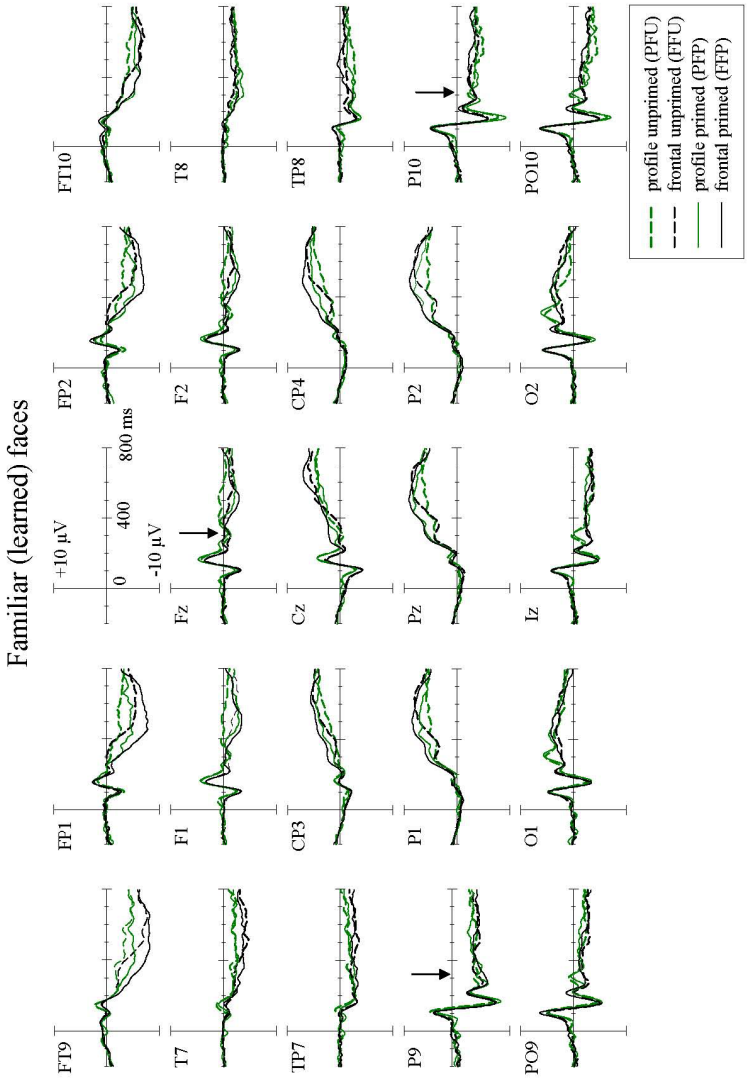


Figure 25: *Experiment III/2: ERPs for familiar frontal and profile targets in primed and unprimed conditions*

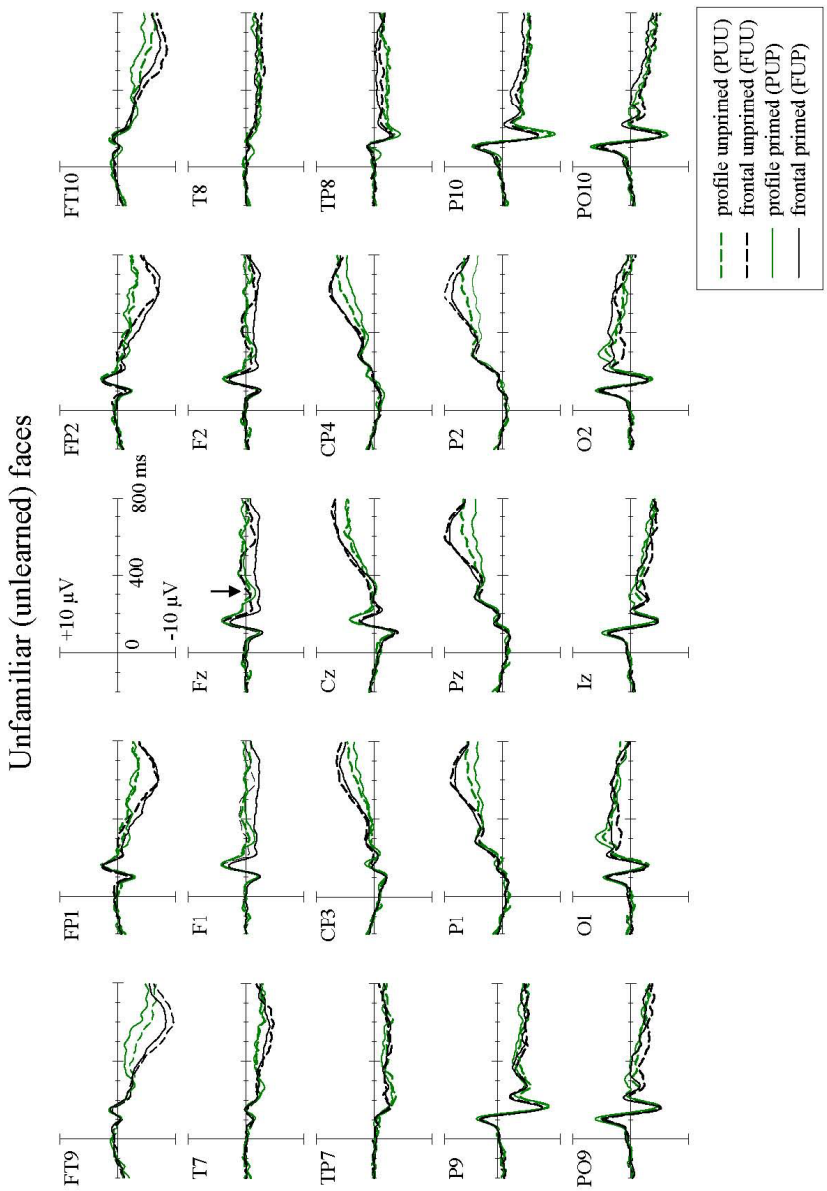


Figure 26: *Experiment III/2:* ERPs for unfamiliar frontal and profile targets in primed and unprimed conditions

Table 25: *Experiment III/2: Results of the ANOVA for amplitude measures of the repetition ERP components*

		Time segments (ms)																
Source	df	80-120	140-220	220-240	240-260	260-280	280-300	300-320	320-340	340-360	360-380	380-400	400-420	420-440	440-460	460-480	480-500	500-550	550-600	600-700
All conditions:																				
Learning view	57, 399		2.28*			2.29*	1.95(*)	2.67*	2.29(*)								4.45*	6.00**	7.96**	6.40**
Familiarity	57, 399							2.89*	3.68**	3.75**	3.89**	4.75***	6.94***	11.35***	12.98***	8.05***	5.53**	5.50**		
Repetition	57, 399						4.04**	5.20***	7.34***	7.23***	7.71***	9.35***	7.59***	6.98***	5.67**	5.64**	6.38***	2.94*		
Familiarity x Repetition	57, 399						2.20*	3.76**	4.67**	4.41**	3.56**	3.20*	2.83(*)	2.55(*)	2.63(*)	2.53(*)				
Familiar:																				
Learning view	57, 399						2.85**	3.78**	2.60*								2.77*	3.85**		
Repetition	57, 399						4.09**	6.87***	9.09***	8.82***	7.90***	8.31***	7.56***	7.90***	8.18***	6.86***	5.98***	5.94**	2.96*	
Frontal : FFP - FFU	57, 855						3.31*	4.72**	6.61***	8.96***	9.00***	9.62***	9.39***	9.18***	9.01***	7.05***	5.16***	3.15*		
η_p^2							.18	.24	.31	.38	.38	.39	.38	.38	.37	.32	.26	.17		
Profil : PFP - PFU	57, 399							3.14**	5.36***	4.46***	3.85***	3.89***	3.51*	4.05**	4.07**	3.43**	3.97**	4.25**	4.12**	
η_p^2								.31	.43	.39	.35	.36	.33	.37	.37	.33	.36	.38	.37	
Unfamiliar:																				
Learning view	57, 399																3.47*	4.25*	8.82***	7.78***
Repetition	57, 399						2.37(*)	2.49*	3.14**	2.10(*)		2.19(*)	2.12(*)							
Frontal : FUP - FUU	57, 855							4.03**	5.13**											
η_p^2								.21	.25											
Profil : PUP- PUU	57, 399																			

(*) $p < .10$ (Trend); *$p < .05$*; **$p < .01$; ***$p < .001$; Bonferroni-corrected α - level for pairwise comparisons; not significant (n.s.) F-values not listed; η_p^2 = explained variance (effect size); FFP / PFP - frontal / profile familiar primed; FFU / PFU - frontal / profile familiar unprimed; FUP / PUP - frontal / profile unfamiliar primed; FUU / PUU - frontal / profile unfamiliar unprimed; Interactions with learning with never reached significance and are therefore not listed.

Repetition priming of unfamiliar targets caused a significant effect of repetition priming from 300 to 340 ms, when frontal and profile targets collapsed. Still, a transient component, that is temporally limited and corresponding to the ERE was not recognizable

for unfamiliar targets. Separate analyses of frontal and profile targets revealed that repetition priming of unfamiliar frontal targets caused a parieto-central positivity and a fronto-central negativity that reached significance only in time segments 300 to 340 ms. Pair wise comparison of frontal familiar and unfamiliar faces in time segments 300 to 340 ms reached significance, *F*s (57, 855) = 3.94 and 4.75, *p*s < .01. Repetition priming of unfamiliar profile targets caused a more temporo-parietal positivity and a fronto-central negativity. Still, pair wise comparisons of unfamiliar profile targets between primed and unprimed conditions failed to reach significance, *F*s < 1.

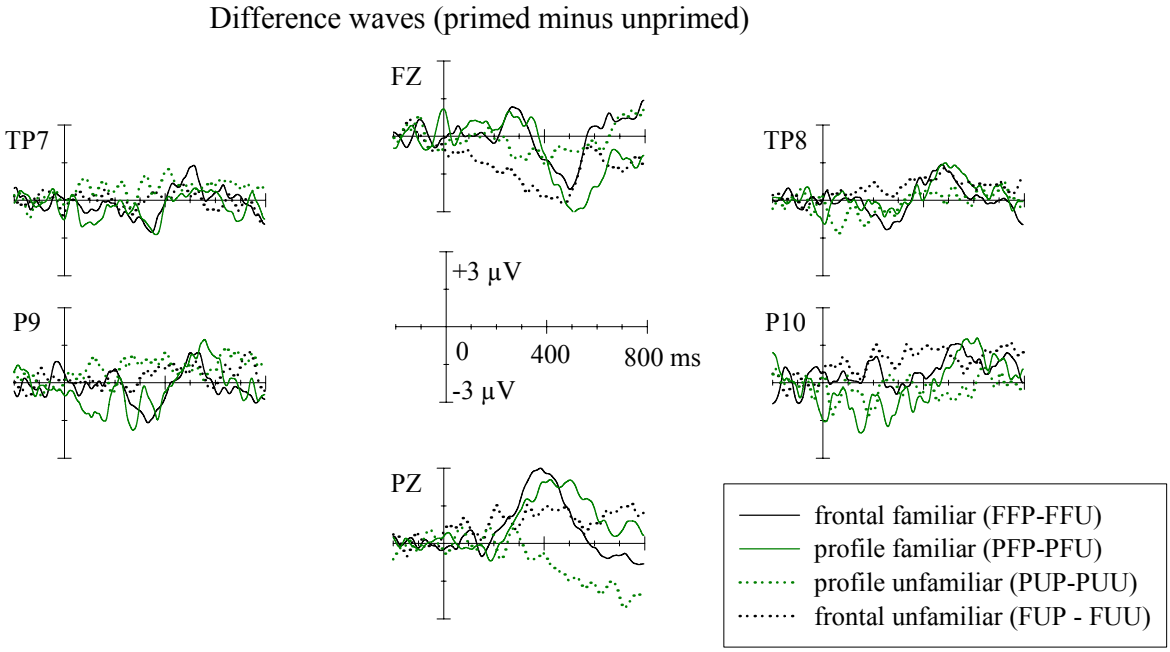


Figure 27: *Experiment III/2: Difference waves (primed minus unprimed) for familiar and unfamiliar targets*

Hemispheric differences in repetition effects:

For frontal familiar targets a main effect hemisphere was found in time segments starting from 220-240 ms, *F* (24, 360) = 22.67, *p* <.001, to 500-550 ms, *F* (24, 360) = 43.42, *p* <.001. From 320-340 ms, where the ERE was determined, the hemispheric effect was significant, *F* (24, 360) = 33.27, *p* <.001. *Table 26* reveals that the effect of hemisphere is caused by a slight left hemispheric lateralization. The lateralization effect to familiar profile targets is comparable to the lateralization to frontal targets. From 220-240 ms onwards ANOVA revealed a main effect hemisphere, *F* (24, 168) = 10.99, *p* <.001, and lasted until 550-600 ms, *F* (24, 168) = 15.58, *p* <.001. For time segment 320-340 ms where

the ERE was determined a main effect hemisphere was significant, F (24, 168) = 17.23, p <.001. This is characterised by a slight left hemispheric lateralization as exemplified by *Table 26*.

Table 26: *Experiment III/2: Mean peak latency (in ms) and amplitude (in μV) for the ERE*

	ERE					
	Fz		P9		P10	
	L(SD)	A(SD)	L(SD)	A(SD)	L(SD)	A(SD)
FFP - FFU	312 (22.6)	1.7 (2.8)	335 (29.0)	-2.4 (2.3)	325 (30.5)	-1.4 (2.5)
FUP - FUU	337 (34.3)	0.5 (2.0)	333 (33.3)	-0.3 (2.1)	329 (33.8)	-0.3 (2.7)
PFP - PFU	325 (20.6)	1.2 (2.3)	331 (31.0)	-1.9 (2.9)	324 (29.5)	-1.6 (2.6)
PUP - PUU	334 (27.4)	0.6 (2.8)	330 (34.4)	-0.2 (1.8)	329 (23.5)	-1.0 (2.6)

FFP / PFP - frontal / profile familiar primed; FFU / PFU - frontal / profile familiar unprimed; FUP / PUP -frontal / profile unfamiliar primed;FUU / PUU - frontal / profile unfamiliar unprimed;

ERE – Peaks and Latencies

Peak detection for the ERE was determined using difference waves from 250 to 350 ms as maximum of positive value at Fz and of negative values at P9/P10. Results are compiled in *Table 26* and showed a repetition priming effect for frontal and profile familiar targets, that reconciles the ANOVA results (*Table 25*). For frontal targets ANOVA results revealed an ERE from 280 ms onwards but strongest in the time segment 320-340 ms. Peak latencies were found at 312 ms for Fz (1.7) and 335 ms at P9 (-2.4 μV), where the effect was most pronounced. Peak latency to profile targets was at 325 for Fz (1.2) and at 331 ms for P9 (-1.6 μV). Peak latency and amplitude differences for frontal and profile familiar targets did not reach significance, Fs < 1.

To provide a complete overview peak latencies in the same time window to unfamiliar target faces are outlined in *Table 26*. ANOVA revealed a repetition priming effect to unfamiliar frontal target faces most pronounced in time segment 320-340 ms. Nonetheless, at those electrode sites outlined in *Table 26* the effect is close to the baseline.

3.1.4.2.3.2 LRE

With reference to familiar frontal and profile targets the ERE was accompanied by a subsequently evoked parieto-central positivity and a prefrontal negativity, that appeared from 340 ms onwards and lasted until 600 ms (*Figure27*). For frontal familiar targets the LRE was strongest in time segment 400-420 ms (explained variance 39%) and lasted until 500-550 ms. To profile familiar targets the effect reached its maximum somewhat later in time segments from 420 to 460 ms (explained varianze 37%). Pair wise comparisons between the LREs for frontal and profile targets did not yield significant differences, *F*s < 1. It lasted until 550-600 ms. A more precise determination of the LRE is provided by topographical differences in reference to the ERE in the following chapter.
For unfamiliar targets a temporo-parietal positivity combined with a fronto-central negativity was detectable from 280 ms onwards and lasted until 500 ms, but failed to reach significance from 340 ms onwards.

3.1.4.2.3.3 Topographical analysis

To determine whether the repetition effects that correspond to the ERE and to the LRE are topographically different and reflect different stages in face processing, scaled differences between the primed and the unprimed conditions were analyzed per time segments, identical to the way time segment ANOVAs had been performed. In *Figure 28* topographies to scaled differences are compiled according to the results as outlined in the following.

Topographies for familiar frontal targets were analyzed and did not differ for consecutive time segments from 260 to 550 ms, *F*s < 2. The comparison of the time segment 320-340 ms where the ERE was determined revealed significance to time segments 440-460, 460-480, 480-500 and 500-550 ms *F*s (57, 855) = 3.11, 3.56, 4.39 and 3.66, *p*s <.01 and .05. As pair wise comparisons of the unscaled mean amplitudes (*Table 25*) yielded highest effect sizes in time segment 440-460 (37%) relative to the other time segments that turned out to be topographically different from the ERE. Therefore, time segment 440-460 ms was chosen to represent the time segment were the LRE for frontal familiar targets was most pronounced.

For familiar profile targets topographies of consecutive time segments were topographically indistinguishable from 300 to 420 ms and from 440 to 600 ms were, *F*s < 1. Topographies from 400-420 to 420-440 ms differed significantly, *F* (57, 399) = 1.83, *p*

<.05, suggesting that there is a transition from the decreasing ERE and an increasing LRE. The ERE time segment 320-340 ms differed from time segments 500-550, F (57, 399) = 2.62, p <.05, and from 550-600 ms F (57, 399) = 2.75, p <.01. Pair wise comparisons of primed and unprimed profile targets (*Table 25*) yielded highest effect sizes (explained variance 38%) in time segment 500-550 ms. Therefore, the time segment 500-550 ms was chosen to represent the LRE for profile target faces.

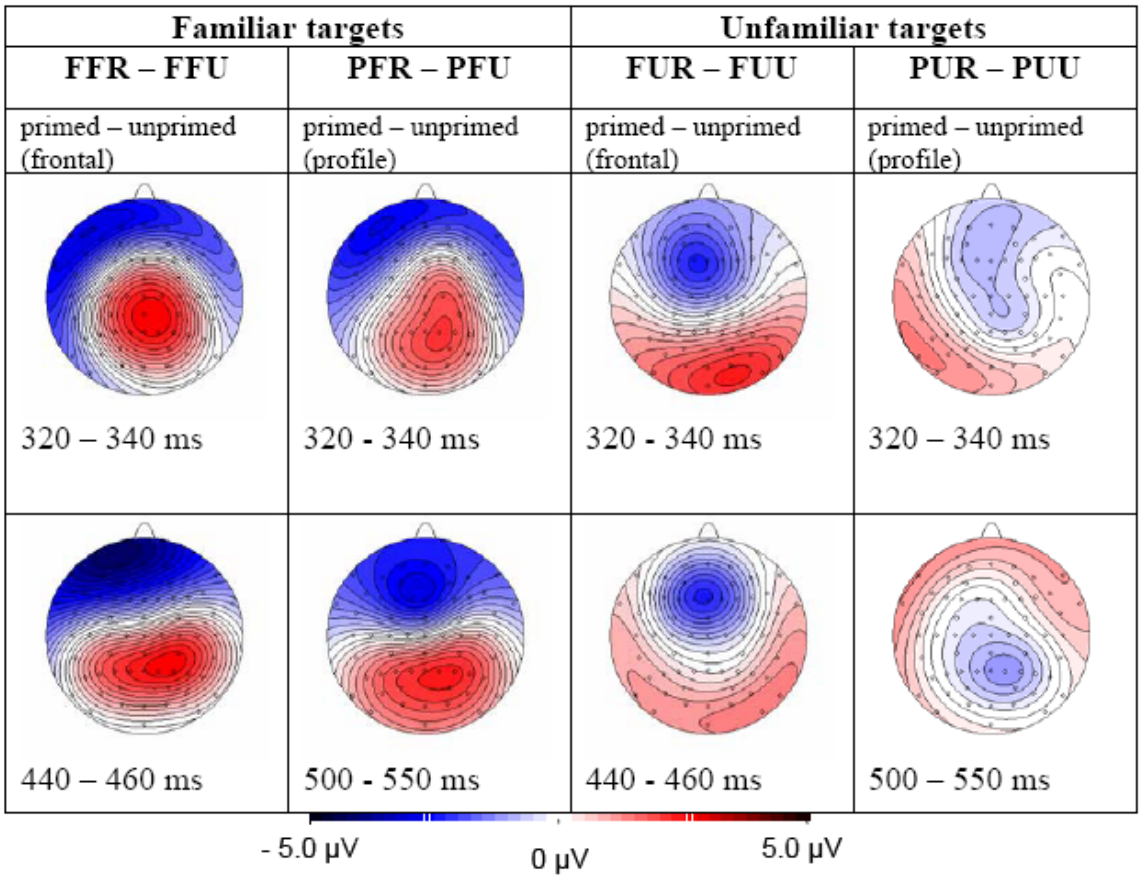


Figure 28: *Experiment III/2: Voltage maps of ERP difference waves between primed and unprimed conditions showing the ERE and LRE time segments. Spherical spline interpolation was used. Equipotential lines are separated by .25 µV.*

Comparing frontal and profile topographies the LRE for profile target faces began later with a longer time period from 360 to 500 ms where early and late portions of the repetition priming effect overlap. Pair wise comparisons of topographies for frontal and profile targets per time segment revealed that they are indistinguishable, Fs < 1, and, therefore, have the same neural source.

ERPs for unfamiliar targets did not show separable modulations of a repetition effect. An increased negativity at fronto-central electrodes and a temporo-parietal positivity was

significant from 300 to 340 ms concerning the unscaled amplitudes. A topographic analysis of these two consecutive time segments did not yield any significant results, *F*s > 1. The comparison of the repetition priming effects found for frontal familiar targets as corresponding to the ERE with the effect found for unfamiliar frontal targets in time segments 300-320 and 320-340 ms revealed significant differences for both time segments, *F*s (57, 855) = 3.83 and 4.51, *p*s <.01. Finally, the topographies found for unfamiliar targets from 300 to 320 ms were compared to topographies for frontal familiar targets that correspond to the LRE. This also revealed significant differences, *F*s (57, 855) = 1.96 and 2.61, *p*s < .10 and .05. Thus effects to familiar and unfamiliar targets found in these time segments are of different neural origin and reflect different processes.

3.2 Discussion

Experiment III focused on the viewpoint-dependency of structural representations for faces in LTM stored within FRUs [Bruce, 86c]. The validation of a repetition priming paradigm with backward masking using unfamiliar face masks in Experiment I and II yielded an ERE that signals the activation of facial representations in the LTM . In Experiment III this paradigm was used to test the sensitivity of the ERE to changes in viewpoint from prime to target (frontal to profile and vv.) and to compare directly the EREs resulting from the frontal and profile learning views. Face recognition across extreme view changes allows for conclusions about the way in which facial representations are stored in memory with respect to dimension and content. To observe repetition priming in RTs and ERPs of target faces, preceded by their 90° deviant view that was unfamiliar would indicate that faces are stored in a viewpoint-independent way, rather than by viewpoint-dependent two-dimensional images. An ERE which is topographically indistinguishable for profile and frontal targets would support the idea of consolidation of features and configuration provided by these different views into a single representation, as assumed by Bruce and Young [Bruce, 86c] with respect to FRUs.
Experiment III combined two recognition sessions. Recognition session 1 was aimed at the EREs dependency with respect to changes in viewpoint from prime to target and its properties concerning the frontal and profile learning views. Recognition session 2 was designed to analyze the specificity of the ERE to familiar faces. An ERE that is specific to learned faces, in contrast to the absence of an ERE for unfamiliar faces, would underpin the success of the learning session prior to the experiment and would validate the

representation-based interpretation of the ERE as found in recognition session 1. In the following discussion the results of recognition session 1 and 2 are discussed consecutively. This is followed by a conclusion concerning the success of formation of facial representations and the generalization from a single face image to novel views with respect to the learning view. Finally, the access of facial information that is invariant to changes in viewpoint will be considered.

3.2.1 Viewpoint-dependence of the ERE

3.2.1.1 Behavioural Data

When compared to Experiment I and II, RT's and PEs where higher and differences between primed and unprimed targets where smaller in recognition session 1 of Experiment III. First of all this can be attributed to the semantic decision task that had to be performed in recognition session 1 which was compared to the familiarity decision task in recognition session 2, the more difficult task. In addition the stimuli were less distinctive and presented without external features which made a fast and correct decision more difficult. The distinctiveness of a face affects speed and accuracy in activating the FRUs, caused by the amount of overlapping facial features within a group of different faces [Burton, 90] [Valentine, 91]. The more facial features overlap the longer the RTs towards the target face e.g. [Valentine, 86] [Bruce, 93] [Valentine, 92] and the smaller the recognition rate [Wickham, 00]. Low distinctiveness might have a cumulative effect on the difficulty of a task. Moreover, recognition performance depends on the information that is given during the learning procedure. Top-down effects in face learning were demonstrated by Bonner, Burton, Jenkins and McNeil [Bonner, 03b]. The authors associated unfamiliar faces with either a character from the popular television cartoon "The Simpsons" or an unfamiliar name. Faces associated with a Simpsons' character were more confidently recognized. Thus, prior knowledge about a person's identity can enhance learning of a new face. According to that Kaufmann, Schweinberger and Burton [Kaufmann, 09] found better recognition performance for faces learned with semantic information compared to faces without such information. In Experiment III the sparse information given by home town, that was for half of the targets "Rome" and the other half "Paris" may interfere with the present recognition performance.

RTs and PEs to profile targets were generally higher compared to the frontal targets. This was also found to be significant for RTs in a study by Bruce et al. [Bruce, 87b], whereas

other research found comparable results for the profile and frontal view for RTs and error rates [Hill, 97] [Liu, 02b] [O'Toole, 98]. This seems plausible when face recognition per se is suggested to be based on both, on configural and on featural information. When only half of the configuration is preserved and the other half is occluded as it is the case for profile faces it might be based on featural information mainly (e.g. nose or chin, shape of the profile). Hence, irrespective of repetition priming and task (as the familiarity decision revealed the same difference in performance data; see 3.2.2.1), recognition rate was better for frontal targets, because of the availability of facial configuration integrating facial features.

A repetition priming effect in RTs was hypothesized for both targets that were learned from the frontal, and those that had been learned from the profile view (hypothesis 1, see 3.1.1.1). Faster RTs to targets that were primed by the same and a 90° deviant view were expected. The effect of repetition priming was hypothesized to be smaller compared to the view-same condition. The results only partly confirmed these hypotheses. Descriptively repetition priming with the same view facilitated RTs for frontal and profile targets according to what was expected. Yet, the effect of repetition priming in the view-same condition reached significance for profile targets only or when frontal and profile targets were collapsed. One explanation for why the repetition priming effect for frontal targets did not reach significance could be a Type II error. Compared to the size of repetition priming effects for famous faces in Experiment I (172 and 187 ms) and II (213, 262 and 289 ms) and in previous studies [Boehm, 06a] [Boehm, 06b] [Pfütze, 02] [Schweinberger, 95], the repetition priming effect for this learned stimulus material was rather small (recognition session 1: frontal targets 45 ms and profile targets 92 ms in the view same condition, recognition session 2: frontal targets 94 ms and profile targets 81 ms). The difference between repetition priming for frontal and profile targets was due to the semantic decision task (recognition session 1) not being observed in the familiarity decision task (recognition session 2). There, the effect of repetition priming in RTs was somewhat larger for frontal compared to profile targets, as will be discussed in 3.2.2.1. For frontal targets the view change was accompanied by somewhat slower RTs in the primed condition (45 ms), which failed to reach significance. The simplest explanation for the absence of repetition priming in the view change condition was that the activation of single features by the profile face as a prime does not cause any facilitation for the related

frontal target face. Still, Boehm [Boehm, 06a] [Boehm, 06b] did demonstrate repetition priming with intervening unfamiliar faces, when a familiar (learning procedure two days before test) target face was preceded by an inverted face. Inverted faces and profile target faces have in common that the provided information is rather feature- than configuration-based e.g. [Maurer, 02] [O'Toole, 94] [O'Toole, 98]. According to Boehm et al. [Boehm, 06a] [Boehm, 06b] for familiar target faces that are preceded by a prime which is rotated 180° in plane its features facilitate the repeated recognition of the target face even if the face was learned by only one view, comparable to the Experiment III. Even though there was no repetition priming in RTs, PEs were lower (4%) in the primed condition compared to the unprimed condition. Subjects were not faster, but more accurate in their semantic decision (home town) towards the frontal target in the view changed condition. The related but unfamiliar view that preceded the familiar target facilitated the accuracy of the semantic decision. This reconciles previous results as compiled in *Table 1* (1.3.3), where most of the studies found that viewpoint-invariance referred to accuracy rather than speed [Bruce, 82] [Davies, 78] [Moses, 96] [Patterson, 77]. Concerning these matching-to-sample tasks when the view of the target was the unknown view, accuracy was still above chance level, even under extreme changes in viewpoint e.g. [Hill, 97] [Troje, 96] [Valentin, 97] [Valentin, 99] [Valentin, 01]. In the present experiment the view of the prime stimulus was changed, whilst the target's view was learned prior to the experiment. For frontal and profile target faces PEs were not generally higher when the view was changed between prime and target. Following Bülthoff and Edelman [Bülthoff, 92] two-dimensional representations of objects or faces demand a transformation process between different views. Higher RTs as well as higher error rates are predicted with larger extents of view changes between two representations. Extreme changes in viewpoint would cause an error rate around chance level particularly when only one view had been previously encountered before (see 1.3.2.2). This assumption does not reconcile the results concerning PEs in this study as for frontal target faces a repetition priming effect in PEs in the view-changed condition was found. This is more in line with Ullman [Ullman, 89], who postulated-viewpoint-dependency for RTs and viewpoint-invariance for error rates at least for basic object categories. For faces Bruce and Young [Bruce, 86c] and Moses, Ullman and Edelman [Moses, 96] suggest the storage of different face images in an interdependent manner to extract three-dimensional information (see 1.3.1.2).

For profile targets there was a repetition priming effect in the view-same condition which was expected and might be based on the repeated activation of single features. The fact that repetition priming reached significance for profile targets in contrast to frontal targets has to be considered. Repetition priming for profile views might be primarily based on single outstanding features (e.g. shape of the nose, shape of head) while recognition of frontal targets might be primarily based on configuration and subordinately on features. This might be because for profile targets only half of the configuration is preserved. Although frontal faces provide the more complex facial information by full configuration, the low distinctiveness between the individual faces impedes facilitation of the activation of the correct FRU. Accordingly, the repetition priming effect is larger for profile target faces because it is predominantly based on outstanding features that are easier to extract and only subsidiary on configural information compared to frontal targets.

In the view-changed condition, when the profile target was preceded by its frontal view the differences in RTs and PEs between primed and unprimed targets were negligible. RTs were the slowest compared to the other conditions. Poor recognition performance in conditions where the view was changed from studied profile views to unstudied frontal test views was a consistent finding in previous studies [Bruce, 86c] [Hill, 97] [O'Toole, 94] [O'Toole, 98] [Valentin, 97] [Valentin, 99] [Valentin, 01]. O'Toole et al. [O'Toole, 94] [O'Toole, 98] described the profile view as a "bad view to transfer", demonstrating poor recognition performance from a profile training view to a frontal testing view. The lack of repetition priming in the view-changed condition indicates that facial features provided by the learned profile view cannot be activated from the related but unknown frontal view [Bülthoff, 92] [Wallraven, 02]. As will be discussed in the following, this is reflected by the absence of a repetition priming effects in ERPs when a profile learned target was primed by the related frontal view. In summary, results suggest, that the retrieval of facial information across large changes in viewpoint is dependent on the view that was learned before, which was demonstrated previously by Troje & Bülthoff [Troje, 96] or Valentin et al. [Valentin, 99]. Hence, viewpoint-invariance in face recognition is moderated by learning view.

3.2.1.2 ERPs

3.2.1.2.1 P100

According to hypothesis 2 (see 3.1.1.1) learning view should affect the P100 as this potential reflects early visual processing and is sensitive to physical variations within the stimuli e.g. [Itier, 02]. In line with these expectations the P100 peak amplitude in the present experiment was somewhat larger and its latency was delayed for profile target faces. This can be explained by a mean luminance that was smaller for profile targets compared to the mean luminance for frontal targets. Moreover, this supports previous studies, where the P100 was found to be sensitive to face inversion. Both rotations in plane and rotations in depth influence holistic processing. Information about facial configuration is not available any more or is at least diminished by rotation. Face inversion compared to the upright condition caused a P100 that was delayed in latency and increased in amplitude [Itier, 02] [Itier, 04a] [Linkenkaer-Hansen, 98]. The mean amplitude of P100 was insensitive to repetition priming or view change between prime and target, which supports hypothesis 3 (see 3.1.1.1) and is consistent with the results found in Experiment I and II and in previous studies e.g. [Itier, 02] [Pfütze, 02] [Schweinberger, 02a]. Comparable to Experiment I and II a right hemispheric preponderance was found in P100, being independent of learning view but influenced by view change between prime and target. As outlined before (see 2.1.4.2 and 2.2.4.2) the main effect hemisphere might be due to the way in which the stimuli had been edited. As all stimuli were presented on black backgrounds which highlights the facial form. In Experiment III additionally hair was removed which emphasized the form of the head. The P100 was associated with perception of holistic aspects of a face and facial form e.g. [Itier, 02] [Itier, 04a], while the perception of form-specific aspects was correlated to right occipital areas [Pobric, 07]. The hemispheric preponderance was slightly stronger when the view was changed between prime and target irrespective of the learning view of the target. This can be associated with the modulation of visual spatial attention processes e.g. [Heinze, 94] [Mangun, 95] [Rossion, 99b].

3.2.1.2.2 N170

N170 to frontal and profile targets was larger and delayed when the view changed from prime to target. This might be due to structural discrimination processes between mask and

target. Since the view of the mask always conformed to the view of the prime, the view change between prime and target always accompanied a view change from mask to target irrespective of the primes' repetition. Campanella et al. [Campanella, 00] found the N170 to be larger when two different faces where presented subsequently compared to the presentation of the same images or identical but morphed faces. This N170 modulation was explained in that subjects in the condition where two different faces where subsequently presented were confronted with two different identities by the perceptual system. Two different perceptual analyses had to be performed successively. Following that, in the present experiment, two different analyses by means of a primarily configuration-based (frontal mask) or a more feature-based analysis (profile mask) had to be performed. Another explanation for a reduced N170 component when the view was the same between prime and target and an increased amplitude when view changed from prime to target, and hence from mask to target, might be an adaptation of the neural structures responsible for N170 generation to the stimulus shape when the view did not change [Kovács, 05] [Kovács, 06]. As previous results revealed the sensitivity of the N170 to structural differences (feature removal, features used only, scrambled faces, inversion,) of facial stimuli e.g. [Bentin, 96] [George, 96], a larger amplitude and a delay in latency for profile targets was hypothesized (hypothesis 2, see 3.1.1.1). Moreover, there are previous studies that have demonstrated larger and delayed amplitudes for inverted faces e.g. [Itier, 02] [Itier, 04a] [Leder, 00] [Linkenkaer-Hansen, 98] [Rossion, 00b] [Schweinberger, 04] and larger N170 amplitudes to "Thatcherised" faces [Carbon, 05]. This was explained by slowed down structural encoding when the face was presented inverted, which disrupted the processing of configural information. In the present experiment the N170 was delayed for profile targets, still, its amplitude did not vary according to learning view. This contradicts the hypothesis. On the one hand, this might be due to configural processing that is reduced but might be still possible for profile targets by means of, e.g. eye, nose and mouth relations. On the other hand based on the differences found in previous studies, this might be a Type II error caused by higher PEs to profile targets and the moderate size of the difference that was expected. Yet the result confirms the finding by Boehm et al. [Boehm, 06a], who did not find a difference in the N170 for inverted faces compared to upright faces.

As in Experiment I and II the N170 was not sensitive to repetition priming, what confirms

hypothesis 3 (see 3.1.1.1). This insensitivity was also found in previous studies [Deffke, 07] [Pfütze, 02] [Schweinberger, 95] and underpins the association of this potential with structural encoding as part of the perceptual process, rather than retrieval of previously encoded stimuli. A right hemispheric lateralization was not found in contrast to the results found by Pfütze et al. [Pfütze, 02].

3.2.1.2.3 Repetition priming effects

An effect of repetition priming was hypothesised from around 200 ms onwards until the end of the recording epoch (hypothesis 3, see 3.1.1.1). The effect of repetition priming was expected to be still significant, but smaller, when view was changed from prime to target. This was hypothesized for both frontal and profile targets. The results instead yielded a threefold interaction of learning view, view change and repetition priming. Repetition priming showed itself to be dependent on learning view and view change from prime to target. A main effect of repetition priming was significant from 340 to 380 ms only. In general the effect of repetition priming was weak, which is in contrast with Experiment I and II of the present thesis and with previous results e.g. [Boehm, 06a] [Herzmann, 07] Pfütze et al. [Pfütze, 02]. As outlined for RTs and PEs this might be caused by the difficulty of the semantic decision task, the highly similar stimulus material, where external features were removed (see 3.1.2.3.1). The reason that the stimuli had been edited in this way was to focus attention on the internal aspects of the face and to accentuate configural, as well as, single facial features in order that repetition priming would mainly be attributed to the internal features of a face [Bonner, 03a] [Ellis, 79] [Young, 85b]. Yet, taking distinctiveness vs. typicality into account [Burton, 90] [Valentine, 91] [Wickham, 00], it is more difficult to activate the correct FRU and PIN when a group of faces is characterized by similar features. For familiar faces the effect of distinctiveness was assumed to come into operation at a very early processing stage and was found independently of repetition priming [Bruce, 93]. Assuming input to the FRUs via feature units as postulated by Burton et al. [Burton, 90] only the distinctive features lead to activation of the correct FRU and subsequently to face identification. Thus, the activation of the correct FRU takes longer. In the unprimed condition, the prime is not identical or related but might have been perceived as very similar to the target. This could have caused facilitation at least of the activation of the similar or overlapping features. In consequence

to that, and in consideration of relatively high PEs, the effect of repetition priming was very small.

ERE

An ERE was found for frontal targets that were preceded by the same view and by their profile view. While the onset of the ERE is comparable to Experiment I and II of this thesis, the size of the ERE is much smaller. The ERE to frontal targets preceded by their same view was found from 320-340 ms only as a trend, because of the failure to obtain a significant ERE and to avoid a type II error, the GFP was calculated in this time segment. In doing so the ERE was validated by a one-tailed t-Test of the GFP (hypothesis 3, see 3.1.1.1). The topography resembled the topography that was found in Experiment I and II of the present thesis as well as in precious studies e.g. [Herzmann, 07] [Pfütze, 02] [Schweinberger, 95]. The differences in the GFP are related to the ERE as an effect of representation based repetition priming due to the activation of FRUs [Bruce, 86c]. Perceptual-based repetition priming was impeded by the unfamiliar face mask as tested in Experiment I and II of the present thesis.
The ERE to frontal targets preceded by their profile view was found as a trend from 300-320 ms and was validated in the same way as for the view same condition. A one-tailed t-Test of the GFP validated the difference in overall activity between primed and unprimed targets. The topography was comparable to the topography found for frontal target faces preceded by the same view, even when analysis was based on the individual scaling method. The difference in the GFP, that validated the ERE trends for the view changed condition, was smaller compared to the view same condition.
Even though for targets that were learned from the frontal view an ERE after view change was found that was topographically indistinguishable from the ERE in the view-same condition (hypotheses 4 and 5). The EREs found were very weak and were based on the analyses of 20 ms time segments (with a sampling rate of 250 Hz that means five data points per time segment) as the analyses of a wider range of time segments did not yield significant results. Still, the results are in line with previous results that revealed a decreased ERE for initially inverted, as compared to upright faces based on the same neural origin [Boehm, 06a]. According to previous fMRI studies face priming was related to the middle fusiform gyrus and in the lateral occipital face area [Haxby, 00] [Haxby, 01] [Kanwisher, 97] [McCarthy, 97]. The present results are consistent with fMRI studies

[Eger, 05] [Pourtois, 05] and studies with primates [Hasselmo, 89b] [Perrett, 85] that found some areas of the fusiform gyrus or in the STS are associated with viewpoint-independent face processing, while others show activity depending on the viewpoint from which a face is seen. On a neural level experiments of Perrett et al. [Perrett, 85] and Hasselmo et al. [Hasselmo, 89b]) revealed the existence of cell populations in the macaque brain that are insensitive to changes in the viewpoint of a face.
Experiment III of this thesis is the first study that has analysed viewpoint-dependency of the representation-based activation of FRUs. Schweinberger et al. [Schweinberger, 02b] and recently Bindemann et al. (in press) have analyzed the image specificity of the ERE and compared the EREs for famous faces. Inherently, many views of a famous face have been previously encoded. The authors used an immediate prime-target paradigm following view-same and view-different conditions. The ERE decreased when the view was changed between prime and target but did not differ in topography. Yet, immediate repetition priming of the same picture is a combination of both, perceptual-based and representation-based priming. View change between the first and the second presentation diminishes the perceptual-based locus of priming. Residual activation mainly indicates the retrieval of facial representations. Thus the comparison of the EREs for the view-same and the view-changed condition is somewhat biased by preceptual-based priming in the view-same condition, by Schweinberger et al. [Schweinberger, 02b]. Despite only a single view being learned before, the present results are in line with Schweinberger et al. [Schweinberger, 02b] in that an ERE was validated by GFP in the view-same and the view-changed condition. Facilitation in the view-changed condition was detectable by PEs and a change in overall activity that signed an ERE with a latency and topography comparable to the view-same condition. This points towards a viewpoint-independent FRU activation, as predicted by Bruce and Young [Bruce, 86c] and Burton [Burton, 94], as the unknown profile view of the frontal target led to the activation of the FRU that includes configuration and features based on the frontal view. According to Burton et al. [Burton, 99] the smaller size of the ERE for the view-changed condition might be associated with different patterns of FRU activation caused by the image differences of the same face, since priming is only based on the similarities between prime and target.
As the configuration by means of the distances between facial features is susceptible to viewpoint changes, face recognition across extreme changes in viewpoint (40-90°) might

be based on a feature-based processing as supposed by the dual strategy approach by Valentin et al. [Valentin, 97] [Valentin, 99] [Valentin, 01].. Features that are stable across viewpoint changes enable recognition even under extreme viewpoint changes [O'Toole, 94] for overview [O'Toole, 06]. Access to stored features by the unknown profile leading to FRU activation seems to require very little time as there were no latency differences in the EREs found for the view-same and the view-changed condition, which also indicates viewpoint-invariant properties of faces recognition. Even though the topography of the ERE for the view-same condition was indistinguishable from the ERE found for the view-changed condition, they appeared different, making a clear interpretation difficult. If the lack of distinguishable topographies was due to the weakness of the EREs, this would indicate different processes concerning the retrieval of the representation-based information and probably differences in neural activity that are dependent on perspective itself. Still, as a repetition effect was found in the view-changed condition, it can be assumed that representations of a face are connected by a linked neural system. The exact differences might be better analyzed using dipole source modulation or fMRI.
Viewpoint-dependent activation, like configuration-based activation, was found to have a right hemispheric preponderance, whilst the storing of view-invariant aspects, like features, was more pronounced in the left hemisphere e.g. [Burgund, 00] [Eger, 05] [Rossion, 00a]. In the present results a hemispheric asymmetry was not found. Still, because of the weaknesses of the experiment this study cannot contribute to the question of lateralized processing being connected to viewpoint-invariance.
For profile targets a topography which resembles an ERE was found for the view-same condition, but not for the view-changed condition. Although analyses of GFP did not yield any significant results, an ERE characteristic topography for the view-same condition can be described from 280-400 ms. One possible explanation for the repetition priming effect that was found in RTs may be a Type II error concerning an ERE for profile targets in the view same condition. Irrespective of repetition priming it seems to be particularly difficult to remember profile targets, which is reflected by generally higher RTs and PEs, as discussed in 3.2.1.1. Another reason might be individual differences for the recognition of profile faces, that cause a high variance in onset and duration of the ERE impeding a significant effect of repetition priming for profile targets.
There are no results showing an ERE for profile targets available from previous studies.

Itier and Taylor [Itier, 04a] did find an ERE for inverted faces. Schweinberger et al. [Schweinberger, 04] did not find an ERE for target faces that were presented upside down using a discrimination task between butterflies and upright and inverted faces, ape faces and cars within an continuously presentation of stimuli. Schweinberger et al. [Schweinberger, 04] interpreted the lack of an ERE for inverted faces in that they do not have strong representations in memory. Accepted that it was a Type II error that resulted in the insignificance of the ERE for profile targets, for profile faces the development of FRUs might be based mainly on features and shape, as configural information is only available from the vertical axis such as eye-nose-mouth relation [O'Toole, 94] [O'Toole, 98] [Valentin, 97] [Valentin, 99] [Valentin, 01].. When the profile target face was preceded by the frontal view, no effect of repetition priming was found in RTs and ERPs. This result indicates that there is no access of the features provided by the learned profile target from the related, but unknown frontal view. Following that viewpoint-invariance in face recognition might be moderated by learning view, as for frontal learned target faces an ERE for the view-same and the view-changed condition could be validated. On a descriptive level, topographies from 280 to 380 ms resemble a P300 component pointing towards a different process when the view changed from prime to target. In literature, the P300 component was related to task demands [Kok, 01] and context updating by means of increased amplitude whenever one's model of the environment has to be revised [Donchin, 81] [Donchin, 88] when the primed condition caused a context updating because of single features that indicate the relation of prime and target. In the unprimed condition, there are no individual features available that would indicate the relation between prime and target, hindering the process of context updating. Thus, the P300 amplitudes would be larger in the primed condition. The difference between primed and unprimed targets revealed this topography.

LRE

The results concerning the LRE revealed a difference in GFP only for frontal targets in the view-same condition between primed and unprimed targets, only partly confirming hypothesis 6 (see 3.1.1.1). However, in this condition repetition priming facilitated the access to the visually derived and stored semantic information. This might be related to the difficulty of the task in that the semantic information, which only consisted of home town, had to be retrieved. The classification to hometown during the learning task was the only

semantic information that was given. As the LRE increases with the semantic information that is available e.g. [Herzmann, 04] the LRE is rather small, caused by the sparse information that was associated with the facial image in this study. But, because the task was a semantic decision task, at least a moderate LRE was expected. One reason for the LREs weakness could be that participants had learned the face itself but the association of a certain face to the home town, ie “Rome” or “Paris”, was difficult to remember as is reflected by the behavioral data. As the stimuli were less distinctive per se and presented without external features, visually derivable semantic information might be less distinctive and could not be based on external features. Hence the difference between the primed and the unprimed condition was rather small.

When the view was changed for frontal targets, there was no LRE. This finding does not reconcile previous results demonstrating an LRE, although smaller compared to the view same condition, when faces had been presented inverted [Boehm, 06a] or with a different image [Schweinberger, 02b]. In the present study neither the retrieval of semantic information nor, visually derived information was facilitated by repetition priming of frontal target faces by their profile view. On the one hand, this reflects the weak association of the learned faces with the semantic “home town” information as discussed above. On the other hand, when compared with the image changes by Schweinberger et al., [Schweinberger, 02b] the visually derivable semantic information here differs remarkably between the prime and the target, because of the 90° view change. Profile faces reveal different information than the information available from a frontal view, such as facial shape with particular respect to the profile of the forehead nose and chin, lateral hairline and ears. This information is not available in the frontal view and therefore, the access of previously visually derived information as part of PINs [Bruce, 86c] and SIUs [Burton, 90] cannot be facilitated across extreme view changes, as in this study.

For frontal target faces in the view-changed condition this may have caused the lack of repetition priming in RTs in the view changed condition.

For profile targets an LRE was not found in either the view-same, or in the view-changed condition. For the view-same condition this could be a type II error based on weak experimental power. Highest error rates had been found in the semantic decision task to profile target faces. This may account for why the repetition priming effect found in RTs data was not reflected by a significant ERE of LRE. In the time range from 360 to 380 ms

the topography resembles an ERE, although not significant, and without corresponding differences in GFP. There was no later time interval resembling the LRE topography as found in Experiment I and II or in previous studies e.g. [Pfütze, 02] [Schweinberger, 95]. For the view-changed condition the lack of an LRE can be explained by different content of visually derived semantic information, in much the same way as with the view-changed condition for frontal targets (see above).

3.2.2 Familiar specificity of the ERE

Recognition session 2 of Experiment III was to test acquisition and retrieval of facial representations as consolidated in FRUs [Bruce, 86c]. In recognition session 1 the EREs found for frontal target faces in the view-same and the view-changed condition indicated the success of the learning session by means of newly built facial representations already. In recognition session 2 repetition priming in RTs, and an ERE that is specific to faces that were learned and absent for faces that were not learned, confirm the successful formation of facial representations in LTM. Please note that for the familiarity decision task to for profile targets only eight participants were involved in the statistical analyses.

3.2.2.1 Behavioural Data

For both, familiar and unfamiliar targets, participant's reactions to frontal targets were faster and PEs were lower compared to profile targets. This replicates the findings from recognition session 1. For frontal, as well for profile targets, there was a repetition priming effect due to familiarity of the target face. This confirms hypothesis 1 (see 3.1.1.2). Repetition priming did not affect unfamiliar targets and is in line with findings by previous studies that found no repetition priming [Herzmann, 07] or repetition priming to unfamiliar targets that was significantly reduced when compared to familiar targets e.g. [Boehm, 06a] [Boehm, 06b]and Experiment I of the thesis. The absence of an effect of repetition priming for unfamiliar faces indicates the elimination of perceptual-based priming by the unfamiliar face mask and supports representation-based accounts of repetition priming for familiar faces.

For frontal targets RTs and PEs differed with respect to familiarity in the primed and unprimed conditions. Participants judged unfamiliar faces in the unprimed condition somewhat faster compared to familiar faces. This corresponds to higher PEs for familiar faces in both primed and unprimed conditions. Taken together this pattern reflects

uncertainty in recognizing familiar targets.
RTs for profile targets only differed in the primed conditions, while RTs for familiar and unfamiliar targets in the unprimed condition were comparable. PEs were not affected by familiarity. For familiar profile targets, repetition priming speeded RTs while error rates were increased for primed targets compared to unprimed targets, suggesting a speed-accuracy trade-off [Rinkenauer, 04]. Compared to frontal targets the pattern of behavioural data for profile target faces indicates that the formation of facial representations and their retention and retrieval from LTM is more difficult for the profile view. It showed generally slower RTs and higher PEs as found and discussed in recognition session 1 of the present experiment. The uncertainty for familiar faces might be moderated by the semantic information given during the learning session e.g. [Bonner, 03b] see 3.1.2.3.1 and the short delay between learning and recognition session, as the consolidation interval between acquisition and recognition session is an important moderating variable for the formation of structural codes e.g. [Herzmann, 07] [Okada, 03]. In this experiment, a consolidation interval of only 24 h was chosen, relatively short when compared to other studies, that implemented a consolidation interval of two days [Boehm, 06b], one week [Herzmann, 07] or 14 weeks [Okada, 03]. Herzmann and Sommer [Herzmann, 07] found a recognition rate (proportion of hits and false alarms) that still remained high after a delay of one week between the learning and the recognition session. In the present experiment PEs were comparably high, but still, clearly above chance level. Accordingly retrieval of the acquired representations in LTM was reliable but weaker, when compared to e.g. Herzmann and Sommer [Herzmann, 07]. Most notably, the effect of repetition priming was found to be specific for familiar faces in the present data, indicating a successful acquisition of the stimuli.
When compared to the repetition priming effect in recognition session 1 (semantic decision), repetition priming for frontal targets in the present recognition session 2 was somewhat larger when compared to profile targets for the familiarity decision task. This may be due to the task itself, as a familiarity decision is easier to perform than a semantic decision task. As discussed in 3.2.1.1, the effect of repetition priming for profile targets is based on outstanding features mainly, while repetition priming for frontal targets might be based on configuration mainly and only subsidiary on features. Configuration in contrast to features is less distinctive what diminishes the effect of repetition priming. During a

semantic decision task, repetition priming facilitates activation of the link between facial pre-semantic representations and the associated semantic information (home town). This might be easier for outstanding (unique) features and the associated home town, than it is for configuration and home town. (However, this was not reflected in ERPs and may possibly be due to the weak experimental power.) A familiarity decision task does not necessarily demand the retrieval of the association between facial representation and semantic information, the advantage for profile targets concerning the repetition priming effect was not detectable here.

3.2.2.2 ERPs

3.2.2.2.1 P100

As expected repetition priming did not affect this early potential (hypothesis 1, see 3.1.1.2). This is a consistent finding in the present thesis as well as in previous studies e.g. [Itier, 02] [Pfütze, 02]. In contrast to recognition session 1 and to hypothesis 4 (see 3.1.1.2), an effect of learning view was not found, even though slightly larger amplitudes were detectable for profile targets. Following previous results e.g. [Itier, 02] [Itier, 04a] [Linkenkaer-Hansen, 98] that demonstrate larger and delayed amplitudes for inverted faces, comparable amplitudes with respect to frontal and profile view might be a Type II error, caused by the small sample size. The right hemispheric preponderance as consistently found in Experiment I, II and in Experiment III / recognition session 1 was detectable but not significant.

3.2.2.2.2 N170

The N170 amplitude was not affected by repetition priming which conformed to hypothesis 1 (see 3.1.1.2) and previous findings. According to hypothesis 4 (see 3.1.1.2) there should be a main effect of learning view in mean amplitudes and in the latency of peak amplitudes, which was not found in recognition session 1, but is in line with previous findings by e.g. [Bentin, 96] [Itier, 02] [Itier, 04a] [Schweinberger, 04], that showed larger and delayed amplitudes, when the processing of configural information of a face is not possible. In Experiment III the N170 was enhanced and delayed for profile target faces that provide restricted configural information. Similar results had been found for the VPP in so much as this potential was 20 ms delayed for profile as compared to frontal targets [Jeffreys, 91]. The VPP was considered by Rossion et al. [Rossion, 03b] to be the positive

counterpart of N170 (see 1.4.2). As in recognition session 1 and Experiment 1 a right hemispheric effect did not reach significance.

3.2.2.2.3 Repetition priming effects

Repetition priming affected ERPs for learned frontal and profile targets from 280 ms onwards. Topographic analysis revealed EREs and LREs that were indistinguishable for profile and frontal targets and specific for familiar targets. This confirms hypothesis 1 (ERE and LRE) and 2 (familiar specificity) as outlined in 3.1.1.2. For target faces that were unfamiliar, an atypical pattern of topography was found. It was characterized by a fronto-central negativity and a parietal positivity. For unfamiliar frontal targets this was significant from 300 to 340 ms and did not reveal distinguishable topographies across time segments. For unfamiliar profile targets this did not reach significance. In previous studies using an immediate repetition priming paradigm, an ERE for unfamiliar targets was found around 300 ms that resembled the ERE found for familiar targets [Schweinberger, 95] or was topographically distinguishable from the ERE found for familiar faces [Herzmann, 04]. Still, comparison of the EREs, found in these studies, do not resemble the topography found for unfamiliar frontal targets at present. Other studies that used intervening faces between prime and targets found repetition priming effects for unfamiliar targets starting from 320 ms that were characterized by a topography that corresponds to the LRE. This was attributed to visually derived semantic knowledge, for example about age, attractiveness, mood and spontaneous associations e.g. [Pfütze, 02]. But the topography of the difference wave for unfamiliar frontal targets at present neither resembled the LRE characteristic topography found in previous studies nor was it comparable to the LRE found in this study. The topography for unfamiliar faces rather resembled the P300 topography as associated with task demands or context updating due to working memory processes [Donchin, 81] [Donchin, 88] [Kok, 01]. In the case of task demand this seems plausible when the primed condition in contrast to the unprimed condition was the more difficult task. In the unprimed condition an unfamiliar face was preceded by a familiar face. As there was no unprimed condition where a familiar target was preceded by a different familiar face participants were able to conclude the correct answer “unfamiliar” from the change of the learned face as the prime to a different face as the target. When an unfamiliar face was primed, the familiarity decision was more difficult as it required the separation of an unlearned face from the pool of faces learned before. Thus, P300 is more

pronounced in the primed condition. One reason for this may be the homogeneity of the stimuli. Within this kind of stimuli familiar faces can be separated from unfamiliar faces, but not vice versa.

The differences between familiar and unfamiliar faces found at present point towards general differences in processing of familiar and unfamiliar faces. As the stimuli in Experiment III were presented without external features, like hairstyle, one could conclude the perceptual-based repetition effect found for unfamiliar faces in previous studies [Pfütze, 02] [Schweinberger, 95] is based on external features rather than configuration due to internal features [Bonner, 03a] [Ellis, 79] [Young, 85b]. This is compatible with assumptions that, beyond the perception of faces as reflected by P100 and N170, unfamiliar faces are processed for identity in a qualitatively different way than familiar faces [Hancock, 00] [Megreya, 06] [Megreya, 07]. It is incompatible with assumptions concerning a common locus for the processing of facial identity of familiar and unfamiliar faces [Goshen-Gottstein, 00]. Following Hancock et al. [Hancock, 00] and Megreya and Burton [Megreya, 06] unfamiliar face processing does rely less on facial configuration: "...unfamiliar faces are processed only as patterns and are matched in the same way as any other visual stimulus without recourse to any information about faces in general." ([Megreya, 06] pp. 874). Still, as commented by the authors them-selves this is an extreme solution to the problem.

ERE

According to hypothesis 2 (see 3.1.2.3.1) a reliable ERE was found specific to familiar faces for both, frontal and profile targets. As outlined above, there was no comparable component for unfamiliar faces. Both EREs were comparable concerning latency, amplitude, hemispheric asymmetry and topography. For profile targets, this finding is different from previous results for inverted faces. There the ERE did not reach significance, which was interpreted as their weak representations in memory [Schweinberger, 04]. Other studies found the ERE for inverted faces delayed and extended due to the more difficult access to facial representations for these configural changed faces [Itier, 04a]. In Experiment III, differences between EREs for frontal and profile targets in latency, amplitude and topography did not reach significance. Comparable topographies indicate that the EREs for frontal and profile targets, and for frontal targets that were preceded by the profile view, originates from the same neural structures. According to

previous studies these neural structures are located in the inferior-temporal areas including the fusiform gyrus and in the lateral occipital face area [Haxby, 00] [Haxby, 01] [Kanwisher, 97] [Schweinberger, 02b] [Schweinberger, 04]. Harris and Aguirre [Harris, 08] demonstrated in an fMRI study that neural populations in the inferior occipital gyrus and the middle fusiform gyrus encode both, parts and the whole of a face. According to hypothesis 4 (see 3.1.1.2), this points towards the integration of different views (in this case profile and frontal view) into a single representation, namely an FRU, as postulated by Bruce and Young [Bruce, 86c], and would support recent assumptions concerning the convergence of configuration and features into a single representation [Bülthoff, 95] [Collishaw, 00] [Schwaninger, 02] [Schyns, 93] [Wallraven, 02]. Still, with respect to the small sample size of eight participants when frontal and profile targets are compared, the absence of the topographical difference between frontal and profile targets, indicating that these are generated by the same sources, should be interpreted with caution. Support for the congruence of neuronal sources was found in recognition session 1, where ERPs topographies related to repetition priming of the same and changed view were indistinguishable. This was also found when inverted faces were used as prime stimuli [Boehm, 06a]. Itier et al. [Itier, 02] [Itier, 04a] found a delayed and extended ERE, and called it the "reactivation of face processing areas" to inverted faces in reference to upright faces that were characterized by a comparable topography. Although, previous fMRI studies concerning face inversion have shown that the processing of inverted faces was associated with ventral extrastriate regions that respond preferentially to different object classes. Following the present data, processing of inverted faces cannot completely be equated with the processing of profile faces. So far, there are no ERP or fMRI / PET studies that compare directly the topographies or neural sources for stored representations of frontal and profile targets. The present data can be considered as a first step towards analysis of quantitative and qualitative ERP differences and similarities of frontal and profile target faces.

A stronger left hemispheric activation was found for frontal and profile targets. In previous studies left hemispheric lateralization in ERPs due to repetition priming in general was an inconsistent finding. In Experiment 2 the non-masked ERE was correlated with a left hemispheric pronounciation, in line with Boehm et al. [Boehm, 06a] who found the same hemispheric asymmetries in repetition priming. PET and fMRI studies found left hemispheric prepondereance to be correlated with activation of facial parts [Iidaka, 03] [Rossion, 00a] and image and viewpoint-invariant aspects of a face [Eger, 05] [Pourtois, 05] and objects [Burgund, 00]. Left hemispheric lateralization in the present data might indicate that face recognition was primarily based on facial features that enable viewpoint-independent face recognition on the one hand, and discrimination between familiar and unfamiliar on the other. Nonetheless, left hemispheric preponderance was not found in recognition session 1, where the viewpoint-dependence of the ERE was tested directly by view change from prime to target. The association of hemispheric effects on the ERE with viewpoint-dependent, configural processing, and viewpoint-independent, featural processing need further exploration.

According to hypothesis 2 (see 3.1.1.2) and as outlined above, EREs for unfamiliar faces (neither frontal nor profile) were not found. This indicates the elimination of perceptual-based priming by the unfamiliar face mask as well as the lack of representation-based priming after one repetition of an unlearned face. The ERE was confined to familiar faces. This indicates the success of the learning procedure one day before the recognition tasks 1 and 2 had to be performed. Still, the consolidation was comparably short and semantic information given for face classification was low. An ERE specific to newly learned faces was also found when the test followed after the learning procedure immediately [Itier, 04a] or developed by target face repetitions during the time course of the experiment [Tanaka, 06], after two days [Boehm, 06a] or after a longer consolidation phase of one week [Herzmann, 07]. There are a few studies that investigated the retrieval of newly learned faces by imaging methods demonstrating the consolidation interval to be an important moderating variable concerning the brain areas that are involved during retrieval. Consolidation into LTM was indicated by different brain regions that become active when newly learned faces and familiar faces are recognized. Despite similar recognition performance recognition of famous faces involves a widespread network of bilateral brain activations involving the prefrontal, lateral temporal and mesial temporal (hippocampal

and parahippocampal regions) areas as compared to recently encoded faces [Leveroni, 00] [Leube, 03]. At the level of individual neurons in the monkey brain Rolls et al. [Rolls, 89] could show the alterations of response degree in some face selective neurons when the set of stimuli starts as novel and is repeated until it becomes familiar. The strongest changes in firing rate were already found after the first two representations. The authors conclude that changes in the selective responsiveness reflect the tuning of neural response by experience so that an ensemble of neurons provides a long-term representation of familiar faces. Okada et al. [Okada, 03] examined brain activation during retrieval of newly learned faces, 5 min and 14 weeks after encoding. Although there was no difference in recognition rate, retrieval after 5 min was associated with activation within the primary visual cortex, as a brain region engaged during sensory perception while retrieval after 14 weeks was not. The difference in activation was interpreted by the transformation of a pictorial code into a structural code by means of the consolidation of configural and featural facial information according to Bruce and Young [Bruce, 86c]. As the transformation process is time-dependent the consolidation of facial information into structural representations into LTM depends on the interval between encoding and retrieval, which was 24 hours in Experiment III. The ERE's topography, as found in recognition session 2 of the present experiment, resembles the ERE's topography found by Herzmann and Sommer [Herzmann, 07] after a delay of one week between learning and recognition session. Comparing error rates and the size of the present ERE with recognition rate and EREs as found by Herzmann and Sommer [Herzmann, 07] the memory trace here seems to be much weaker. Beside the short consolidation interval, this might be caused by the homogeneity of stimulus material as discussed before (see 3.2.1.1, 3.2.1.2) and the learning procedure itself. The learning procedure included a matching to sample task, where faces had to be classified to their home towns (see 3.1.2.3.1). To achieve the learning criteria all faces had to be classified correctly. Incorrect answered items were appended until the answer was correct. To answer appended items correctly a different strategy might have been used, in that simply the other town was chosen as before. This might be especially the case if only few items are left. Still, the familiar specificity of the repetition priming effect in RT and of the ERE for frontal and profile targets revealing the characteristic topography argue for a successful acquisition and retention of facial representations in LTM from learning to recognition session.

LRE

According to previous findings the LRE was hypothesized to be significant for both familiar and unfamiliar faces (hypothesis 3, see 3.1.1.2), although smaller for unfamiliar faces [Herzmann, 07] [Pfütze, 02] [Schweinberger, 95]. The LRE found in recognition session 2 was specific to familiar faces and absent for unfamiliar faces. Repetition priming that is based on visually derived semantic knowledge was not found for unfamiliar targets. This seems plausible when, comparable to the lack of perceptual-based repetition priming on a pre-semantic level, repetition priming of visually derived semantic codes was based primarily on external features. As the stimuli were edited by hair removal these features are no longer derivable. The LREs for frontal and profile familiar targets were comparable concerning amplitude. The LREs might reflect facilitated activation to associated semantic knowledge as given by the learning session (home town) and of semantic association that was already visually derived and established during the learning session. The delay of the LRE for profile targets is a consequence of the delay as found for the ERE component, although not significant. Further more, it might be attributed to the more difficult retrieval of semantic information for faces shown from a perspective that is rather unusual in terms of a learning task. The LREs for frontal and profile targets did not topographically differ, indicating comparable neuronal sources.

FN400 and LPC

When stimuli are processed repeatedly, explicit and implicit forms of memory occur together, still it is difficult to disentangle processes that are associated with repetition priming and episodic remembering [Boehm, 08] [Paller, 07]. The stimuli in Experiment III had been newly learned which could implicate the episodic retrieval of facial information due to the learning session, rather than the implicit retrieval of structural representations of faces from LTM. Even though, the ERE in the present thesis was used to study perceptual representations of faces due to implicit memory, it also may reflect episodic recollection with respect to the learning phase. The old / new effects may indicate the retrieval of explicit memory to perform the familiarity decision task in recognition session 2 e.g. [Herzmann, 07] [Johansson, 04] see 1.4.1.1, and are reflected by differences in the FN400 and the LPC for familiar, as compared to unfamiliar targets from 400 ms onwards in the unprimed conditions.

The FN400 and the LPC were analyzed to test episodic recollection to the familiarity decision task in recognition session 2. Analysis did not yield significant results in any time segment corresponding to the FN400 and LPC as being associated with processes of item familiarity and explicit recollection e.g. [Herzmann, 07] [Johansson, 04]. This could explain for the high stimulus uncertainty, as a recall of context information with respect to the learning session or the matching to sample task prior to the recognition sessions seemed impossible. The lack of difference between old (learned) and new (not learned) faces in the unprimed condition indicates that the familiar decision task was not simply performed by recollection of the target faces from "the list" of faces to be learned. Repetition priming effects as found in RTs and ERPs were rather based on implicit memory processes and may be due to a facilitated activation within the perceptual representation system (PRS) as containing perceptual codes of the learned faces [Tulving, 90] see 1.4.1.1. Operating on a pre-semantic level, neural changes within the PRS can be produced without conscious remembering. Considering the level of encoding during the learning session and the interval between encoding and retrieval as used in the present experiment, this had little effect on priming as an implicit process, while episodic retrieval as an explicit process was not detectable, at least not when FN400 and LPC were analyzed [Jacoby, 81]. This is what was found by Joyce and Kutas [Joyce, 05], as the ERE varied with memory even when there was no explicit face recognition. The authors found that the FN400 and the LPC became more sensitive to the strength of memory trace due to the process of consolidation. While the number of false alarms decreased and the FN400 and LPC potentials increased over time of consolidation, there was no such effect found for the ERE (N250r) by Joyce & Kutas [Joyce, 05]. This indicates the independence of the ERE component from error rates, and from the FN400 and LPC as correlated to familiarity and explicit recollection.

Differences in neural sources depending on encoding level and episodic or unconscious retrieval of facial stimuli are described by Leveroni et al. [Leveroni, 00] and Lehmann et al. [Lehmann, 04]. Leveroni et al. [Leveroni, 00] compared brain activation during retrieval for famous, newly learned and unfamiliar faces directly. While performance data for famous and newly learned faces were equivalent, recognition of famous faces was associated with a widespread network of brain activations compared retrieval of recently encoded faces. The regions involved in recognition of famous faces as prefrontal and

lateral temporal regions were associated with retrieval of semantic information. Regions associated with recognition of newly learned faces as frontal and parietal regions were related to episodic retrieval.
Lehmann et al. [Lehmann, 04] studied the dissociation between overt and unconscious face processing in FFA area. While the activity of this area during encoding predicts which faces were subsequently remembered or forgotten the FFA activity did not differ according to remembered and forgotten faces during recognition. The FFA activity only differentiated if a face was previously seen or not. This is in line with studies that found the FFA region as the underlying neuronal source for the ERE generation e.g. [Schweinberger, 02b] [Schweinberger, 04].

3.3 Conclusion

3.3.1 Formation of facial representations from a single face image

Recognition session 1 (semantic decision task) yielded EREs for both, the view-same and the view-changed condition for frontal targets, which indicates the existence of newly built representations for frontal targets. In recognition session 2 (familiarity decision task), repetition priming effects were found concerning RTs and the EREs for both, profile and frontal targets that were familiar specific and absent for unfamiliar targets. For frontal and profile target faces this demonstrated the success of the learning session. Despite the consolidation interval that was comparably short and that the semantic information associated with a face was sparse, structural representations by means of FRUs were established. The lack of difference between old (learned) and new (not learned) faces in the unprimed condition (FN400, LPC) indicated that episodic recollection of the faces learned before played a minor role for face recognition in the present study. Considering high PEs, the lack of the FN400 the LPC reflect weakness of the memory trace and stimulus uncertainty. Repetition priming effects found in the behavioural data and in ERPs are due to implicit rather than explicit memory processes even it is difficult to dissociate one from the other [Boehm, 08] [Paller, 07]. The underlying neural activity for recognition of familiar target faces, even if not consciously remembered, might originate from the FFA area [Lehmann, 04]. In previous studies the ERE was related to activity in the FFA area for repetition priming by the same or a different image of familiar faces and hence to activation of their structural representations in memory [Eger, 05] [Schweinberger, 02b]. For unfamiliar faces there were no repetition priming effects verifiable for either RTs or

ERPs. Compared to previous studies that have used repetition priming with intervening faces this is a new finding e.g. [Boehm, 06a] [Pfütze, 02]. One reason for these findings might lie in the stimulus material itself, as presented without any external features in the present experiment. For unfamiliar faces the processing of external features is thought to be equally important as the processing of internal aspects of a face containing information about internal features and their relations and distances among them [Bruce, 86c] [Ellis, 79]. As internal features were not stored and the perceptual-based repetition priming was impeded by backward masking, no repetition priming effect was found for unfamiliar faces. This supports assumptions that the processing of unfamiliar faces is different compared to familiar faces. Beyond facial perception structural representations do not exist for unfamiliar faces e.g. [Hancock, 00] [Megreya, 07]. In summary, the results indicate the success of acquisition, retention and retrieval of the learned frontal and profile faces with the internal facial aspects on one hand. On the other hand the memory trace was still weak which was indicated by a high stimulus uncertainty. Recognition was based rather on implicit than explicit memory processes as indicated by the EREs and the absence of FN400 and LPC.

3.3.2 Viewpoint-dependence and viewpoint-invariance of facial representations

Repetition priming as revealed by recognition session 1 (semantic decision task) and 2 (familiarity decision task) provide insights into the nature of formation and retrieval of facial representations with respect to viewpoint-dependence and viewpoint-invariance. Recognition session 1 tested the viewpoint sensitivity of the ERE and recognition session 2 was to analyze the EREs specificity to familiar (learned) faces in contrast to the absence of an ERE for unfamiliar (unlearned) faces. Recognition session 2 provided a direct comparison of the EREs for frontal and profile targets. Three main conclusions can be drawn: First, at least for target faces that had been learned from the frontal view, the retrieval of facial representations across different views can be characterized by viewpoint-invariance rather than viewpoint-dependence. Beside better performance concerning accuracy in the primed condition an ERE could be validated by GFP for the view-same and the view-changed condition. The EREs were comparable concerning latency and topography. This implicates that theories that rely on the storage of multiple views by means of two-dimensional images and their transformation alone have to be rejected as they postulate the encounter of at least two different views to enable face recognition from

an unfamiliar viewpoint [Bülthoff, 92] [Poggio, 90] [Tarr, 89] [Ullman, 91]. The results also contradict holistic face processing, which defines face encoding and recognition as whole templates, without representing explicit parts [Tanaka, 93]. Following Farah et al. [Farah, 95b] it is the representation of faces as holistic complex patterns that causes the orientation sensitivity of face perception. Although theories that predict immediate viewpoint-invariance based on abstract representations by simple geometric primitives [Biederman, 87] [Marr, 78] are less able to account for face recognition across different viewpoints, humans do encode face parts (components, features) in addition to information about the spatial relationship of facial features (configuration). The notion is that face processing relies on two different routes that are represented by configural information and component information [Collishaw, 00] [O'Toole, 94] [O'Toole, 98]. O'Toole et al. [O'Toole, 94] [O'Toole, 98] and Valentin and collegues [Valentin, 97] [Valentin, 99] [Valentin, 01] concluded that face recognition across different viewpoints relies on the transfer of either configural- or feature-based information, that is individually specific and extracted from the learning view. The kind of information that face recognition relies on depends on the angle of view change. fMRI studies [Eger, 04] [Eger, 05] [Pourtois, 05] demonstrated areas of the fusiform gyrus or in the STS are associated with view-independent face processing. Large changes in viewpoint (above 40°) rely on recognition using features that remain stable across a wide range of viewpoints. Thus, repetition priming for frontal target faces by their profile view might be based on features primarily. The smaller ERE compared to the view-same condition can be attributed to a decrease in priming by configuration. Secondly, viewpoint-invariance in repetition priming across changes in viewpoint was dependent on the learning view indicating that the formation of facial representations in memory is viewpoint-dependent. This result reconciles the findings by Troje & Bülthoff [Troje, 96] and Valentin et al. e.g. [Valentin, 99]. Frontal faces provide complete configural as well as featural information leading to holistic information for a face e.g. [Collishaw, 00]. The frontal information is arranged along two axes, the horizontal and the vertical axis. The horizontal axis provides information, e.g. of eye to eye or cheekbone distance and the vertical axis includes the eye-nose-mouth relation. Profile faces might be better characterized by single features or shape, as only half of the configural information is provided [O'Toole, 94] [O'Toole, 98] [Valentin, 97] [Valentin, 99] [Valentin, 01]. The

profile face information is arranged primarily along the vertical axis by means of the eye-nose-mouth relation. During repetition priming of frontal target faces, by the related but unknown profile view, features that are still visible across changes in viewpoint activate the structural representations from the frontal view and are transferred into their configuration. The configuration of the frontal view was learned along both, the vertical and the horizontal axis. The profile prime provides features arranged along the vertical axis. These features can be integrated in the horizontal axis provided by the frontal target face as it was previously encoded.

During repetition priming of profile target faces by the related but unknown frontal view, configuration and features provided by the frontal view do not activate stored structural representations of the profile view. A transfer from featural and configural information to features that were encoded before by the profile view does not seem to be possible, at least not when the profile view was previously exclusively encountered. .This reconciles O'Toole et al. [O'Toole, 94] [O'Toole, 98] who described the profile view as a "bad view to transfer". As opposed to frontal targets, the information of profile targets was learned along the vertical axis only, while the horizontal arrangement of features, like eye to eye distance is missing and not derivable from the profile view. Following that, face recognition across large changes in viewpoint requires a learning view that provides configuration on both, the horizontal and the vertical axis. Features arranged along the vertical axis need to be integrated into the horizontal arrangement of that features in the frontal view. When the horizontal arrangement was previously not encoded, face recognition seems to be impossible.

Thirdly, facial representations acquired by frontal and profile targets are pooled into a single representation of a face as postulated for FRUs by Bruce & Young [Bruce, 86c]. In recognition session 2 familiar specific ERE was found for faces learned from the frontal and the profile view that were topographically indistinguishable indicating a common underlying neuronal source. This implicates the consolidation of different views within a single identification unit [Bruce, 86c] [Schwaninger, 02] [Wallraven, 02].

To summarize, results confirmed the postulations for FRUs by Bruce and Young (1986). Familiar faces are represented as an interlinked set of structural codes containing information about internal features and their relations among them [Bruce, 86c]. Still, object-centred viewpoint-independent activation can only be predicted, when the learning

view provides feature-based as well as configuration-based information that is stable across changes in viewpoint. According to Burton et al. [Burton, 99] an image change between representations always leads to quantitative differences in repetition priming effects because different patterns of FRUs are activated according to the degree of similarity of prime and target. Viewpoint-invariant, object-centred face recognition is a result of the integration of multiple stored views by means of configural information and features in an interlinked manner. In this sense three-dimensional rather than simply two-dimensional facial information is provided by FRUs.

3.3.3 What supports the access to viewpoint invariant facial information?

As indicated by the results of Experiment III, face recognition from a novel view is dependent upon the view that was previously learned and in a quantitative manner from the similarity between two images by means of the angle of view change. A learning view that provides configural, as well as featural, information enables recognition even when rotation into depth exceeds 45° with respect to the learning view. When the view is rotated from frontal view into depth, many configural- and feature-based aspects get lost, such as eye-base and their relation to other facial parts, width of the nose and mouth. Other aspects appear, however, such as shape and bridge of the nose, when a face is seen in a profile view. Face recognition requires the ability to detect and extract specific invariant properties of a face in order to recognize it under various presentations, for instance resulting from even large changes in viewpoint [O'Toole, 06].
What aspects remain invariant over a large range of viewpoints and what supports their access in novel views? Generalization from a single face image to different views means the extraction of a three-dimensional - object shape from an image that is based on surface information [Moses, 96] [O'Toole, 94]. Depth cue features, such as shading, lighting and texture, stay the same as a part of the 2 ½ sketch according to Marr [Marr, 82] and might enter FRUs during structural encoding of faces [Edelman, 92]. Most important for identification is that the configuration remains the same, such as the eye-nose-mouth-distance, and that these properties are recognizable and extractable [Lowe, 87]. Faces are discriminable from features arranged along a single (vertical) axis and are approximately, symmetrical. This property enables the visual recognition system to discriminate objects on the basis of features along a single dimension. Following the dimensionality-hypothesis by Tarr and Pinker [Tarr, 90] it is this ability that determines when viewpoint invariant-

representations are invoked. Wilson and Farah [Wilson, 03] tested the dimensionality-hypotheses with two-dimensional line drawings rotated clock wise and found that symmetry and a number of featural elements were important factors in obtaining viewpoint-invariance. Symmetry provides redundant information and thus, is thought to be a critical feature to employ viewpoint invariance. This is in line with the results of recognition session 1 of Experiment III. Only when the learning view provided vertical and horizontal information, which included symmetric information, was face recognition across a change in viewpoint possible. Therefore, while face recognition from the frontal learning view to its unknown profile view was possible, face recognition from profile learning view to its unknown frontal view was not.

Poggio and Vetter [Poggio, 92] used the symmetry argument to introduce the idea of transformation of non-accidental or canonical views into virtual views. Provided that an object is roughly bilaterally symmetrical, and the trained view reveals symmetry (as in the case of canonical views), a symmetrical virtual view, from the only known view, might be generated. In that sense learning of only one view of a face might be sufficient for recognition. Schyns and Bülthoff [Schyns, 93] demonstrated that face recognition from a single view is always better when the learned view allows the computation of a symmetrical view. Experiments by Troje & Bülthoff [Troje, 96], as well as those of Hill et al. [Hill, 97] suggest that symmetry acts as an invariance property that may at least reduce the number of views necessary for recognition.

Face recognition across large changes in viewpoint might be due to the fact that information about a face is not completely specified and therefore, generalization from single views can take advantage of prior experience with other faces, seen under a wider range of viewing conditions [Lando, 95]. Thus, generalization to novel views from a single face image can be seen as a co-operation of top-down and bottom up processes [Tarr, 98b] [Vetter, 98]. The use of viewpoint-invariant representations during recognition is also driven by voluntary control, since it is dependent upon different instructions given to the participants during learning and recognition [Wilson, 03] [Tarr, 03]. Wilson and Farah [Wilson, 03] found viewpoint-invariance when subjects were explicitly instructed to take advantage of dimensional features of an object. Spatiotemporal relationship between two representations, i.e. in studies with rotating faces, supports three-dimensional information perception but biases observer's identity decisions, as they showed a tendency to treat

different views as if they were of the same person [Bartlett, 98] [Knappmeyer, 03] [Wallis, 01]. In summary, generalization performance across large changes in viewpoint, when only one example view of a face is available, is supported by the extraction of features and depth cues, nearly symmetrical information along the horizontal axis, consistency of configural information along the vertical axis, explicit task demands, experience with the specific-object class "faces".

4 GENERAL DISCUSSION

4.1 Short review of results

The present thesis focused on the ERE as a marker of pre-semantic facial representations within FRUs [Bruce, 86c] and on the ERE's sensitivity to changes in viewpoint. The ERE can be observed, when familiar faces are shown repeatedly, as an ERP around 250-350 ms that is more positive at the fronto-central and more negative at the inferior temporal sites for the second presentation. The ERE that is evoked by immediate repetition of the same picture of a face e.g. [Schweinberger, 95] and reflects a combination of two dissociable processes, the facilitated access to preexisting representations of familiar faces in LTM and the facilitated perceptual processing due to STM. The ERE was confined to familiar faces when perceptual codes were extinguished between face repetitions e.g. [Pfütze, 02]. The presented experiments used a repetition priming paradigm with backward masking that was intended to impede perceptual-based face priming due to STM and to maintain representation-based priming due to LTM.

Provided that the ERE indicates representation-based priming and hence, the activation of structural representations of faces in memory, the ERE's sensitivity to changes in viewpoint provides answers to the way in which faces are stored in memory – by two-dimensional viewer-centred images or by three-dimensional, object-centred entities. Experiments I and II focused on the validation of the ERE as indicating the activation of structural representations of faces stored in memory. Experiment III analyzed the sensitivity of the ERE concerning changes in viewpoint from the first to the second encounter with a face. In Experiment I a repetition priming paradigm with backward masking by an unfamiliar face mask was used to compare repetition priming for familiar and unfamiliar targets. A significantly larger effect of repetition priming in RTs for familiar faces compared to unfamiliar faces and an ERE that was confined to familiar faces and absent for unfamiliar faces was found. This was interpreted as a result of backward

masking by an unfamiliar face impeding perceptual-based priming due to STM while representation-based priming due to facilitated activation of stored facial representations in LTM remained. Experiment II compared different mask types following the prime immediately as interfering with both pictorial and structural codes (unfamiliar faces), just pictorial codes (scrambled faces), or none (grey rectangle). A graduated pattern of repetition priming effects was found in RT, ERE and LRE, with the smallest for face mask and the largest for the non-mask condition consistently. Repetition priming decreased as the impact of the mask increased. The ERE masked by an unfamiliar face showed a different topography compared to scrambled or non-masked EREs reflecting two different sources of repetition priming: representation-based priming as residual activity in the unfamiliar face mask condition and for the non-and scrambled masked condition the combination of perceptual-based and representation-based priming.
Based on the results of Experiment I and II the repetition priming paradigm with backward masking with an unfamiliar face mask was applied in Experiment III. Experiment III focused upon the ERE's sensitivity concerning view change from prime to target and compared two extreme points of learning views – frontal and profile - directly. Faces were learned from either a frontal or a profile perspective 24 hours before recognition sessions 1 and 2 had to be performed. During the learning session faces had to be classified to the fictive home towns "Rome" or "Paris". Recognition session 1 used a semantic decision task ("home town") for target faces to test viewpoint-dependency of the activation of the newly built facial representations in LTM. Viewpoint-dependence of the ERE was analyzed in that the generalization from the frontal or profile view that was learned to their related but unlearned profile or frontal view was tested. The learned views were either primed by the same or the related but 90° deviant views. Repetition priming of frontal target faces yielded comparable EREs concerning latency and topography for both, the view same and the view changed condition, showing a smaller amplitude for the view-changed condition. Both repetition priming effects were validated by pair wise comparison of the global field power (GFP) between primed and unprimed conditions. The difference in the GFP, which validated the ERE trends for the view changed condition, was smaller compared to the view same condition. Repetition priming for profile target faces did not yield comparable results. Only in RTs was there a repetition priming effect for profile targets primed by the same view that was not reflected by significant repetition effects in

ERPs. This could be due to the high PEs found for profile targets irrespective of recognition priming and thus, to the number trials that had to be excluded from data analyses.

Recognition session 2 allowed the direct comparison of the ERE evoked by frontal and profile target faces that were primed by the same view. Repetition priming combined with a familiarity decision task yielded topographically comparable EREs to frontal and profile target faces. The effect of repetition priming was confined to familiar faces and absent for unfamiliar faces with respect to RTs and ERPs.

The results in recognition session 1 and 2, by means of an ERE after view change for frontal learned targets and the familiar specificity of the EREs indicate, at least for targets learned from the frontal view, viewpoint-invariance and successful acquisition of newly built representations of faces. Using a repetition priming paradigm with backward masking by an unfamiliar face the EREs can be interpreted as being based on the facilitated activation of facial representations in memory.

4.2 General Conclusion

Results from Experiment I and II indicate that repetition priming with backward masking by an unfamiliar face mask is an appropriate tool to extract an ERE that is based on reactivation of facial representations stored in LTM while eliminating the availability of perceptual based information due to STM. Therefore, this paradigm was utilized in Experiment III to study the way in which facial representations are stored. Results of Experiment III allow the following conclusions: Theories that rely solely on the storage of multiple views by means of two-dimensional, viewer-centred images and their transformation have to be rejected as they postulate the encounter of at least two different views to enable face recognition from an unfamiliar viewpoint [Bülthoff, 92] [Poggio, 90] [Tarr, 89] [Ullman, 91]. Likewise, theories that rely on three-dimensional, object-centred representations based on the decomposition of objects into viewpoint-invariant parts [Biederman, 87] or images [Moses, 96] [Ullman, 89] have to be rejected for faces to be recognized on a subordinate level. As an ERE after view change was detectable that was smaller compared to the ERE in the view same condition (recognition session 1) and an ERE for profile and frontal targets was topographically comparable (recognition session 2), the most suitable model for the storage of facial representations should incorporate viewpoint-dependent as well as viewpoint-invariant aspects. Viewpoint-invariant face

recognition depends on the learning view. For targets learned from the profile and primed by the related frontal view repetition priming was not found. This reconciles previous findings by O'Toole et al. [O'Toole, 94] [O'Toole, 98] for overview [O'Toole, 06] and Troje and Bülthoff [Troje, 96] and was related to the reduced amount of configuration-based information in profiles. Profiles rather provide information of the vertical arrangement of features while horizontal relations of features are hidden. Generalization from the learning view to a previously unknown view might be based on features that are arranged along both, the vertical and the horizontal axis. If the horizontal axis is missing during learning, features along the vertical axis cannot be transferred into a view that provides second order relations [Maurer, 02] along both axes.
For targets learned from the frontal view, results reconcile the dual-strategy in face recognition that accounts for face recognition even over extreme viewpoint changes [O'Toole, 98] [Valentin, 01]. Accordingly, face recognition below view changes of 30° is associated with recognition by configuration and face recognition above view changes of 40° involves recognition by features. Facial representations can be assumed to be a combination of image-based views, reflecting their configuration and single features. Comparable EREs across view change and learning views indicate the convergence of featural and configural representations within a single unit [Schwaninger, 02] [Wallraven, 02].
The assumption by Bruce and Young (1986), that FRUs contain an interlinked set of structural codes including configural and featural information for distinct head angles, is supported by the findings of Experiment III. FRUs become active after any view of a familiar face is seen. In that sense they can be characterized as being viewpoint-independent and object-centred rather than viewer-centred [Burton, 94]. If FRUs contain descriptions about single features, their configuration with respect to symmetric (horizontal) and vertical arrangement, about depth cues and shape that is unique for a specific face, three-dimensional rather than simply two-dimensional facial information is provided by FRUs making object-centred recognition possible. Moreover, as face stimuli constitute a set of highly similar objects facial representations by means of FRUs have to capture the subtle variations in features and their configurations that make one face different from all other faces representing faces in a manner that overcomes dramatic changes of the perceptual appearance when expression, illumination or view is changed.

4.3 Further prospects

Some open questions and problems remain unresolved and arise from the present data. The following is a compilation of the problems previously when the results were discussed in detail and give some ideas in respect to follow up studies.
The variations found in repetition priming due to the congruence / incongruence concerning the familiarity between prime and target, illustrate that there are side effects in Experiment I and II that have not been shown before and need replication. These differences were found in ERPs between the time segments where the ERE and the LRE were determined. In Experiment II the mask effects found in the RT for the unprimed condition need replication. The effect of an unfamiliar face mask was opposite to the primed condition as it was associated to the shortest RTs compared to longest RTs unmasked condition. A problem that has to be considered across all the experiments of the present thesis concerns the processing of semantic information as reflected by the LRE that overlaps in time with prior processing stages, as activation of structural representations of a face. This reconciles the assumption of the IAC model by Burton et al. [Burton, 90] of continuous information output to the next processing stage but makes a precise determination of the ERE difficult. Herzmann & Sommer [Herzmann, 07] attempted to deal with this problem by performing microstate analyses of priming effects in ERPs by global map dissimilarity (GMD). Using this method segment borders can be defined by GMD peaks and can be used for subsequent analyses. Additionally the task itself causes accentuation of structural representations or semantic information that is associated with an individual face. For experimental reasons to test view point-dependence in Experiment III/recognition session 1 a semantic decision task was used. Although this kind of task affords face identification on a pre-semantic level it emphasized the activation of semantic knowledge at the same time. Therefore, for follow up studies a familiarity decision task should be used to analyze face recognition after view change. Another problem throughout the presented experiments is topographical analysis that did not provide precise information about location differences in the underlying neuronal sources. Dipole source modeling might provide more precise information. This is especially important with respect to topographic differences for different mask types in Experiment II. Likewise the absence of topographical differences between the EREs for the view-same and the view-changed condition as well as between the EREs for frontal and profile targets is not clear

evidence for common neuronal sources, as it may be a result of the weakness of the effects themselves. At least for Experiment III dipole analyses were intended to be performed within a repetition priming paradigm after image stretching by Bindemann et al. [Bindemann, 08] or Schweinberger et al [Schweinberger, 02b]. Unfortunately, as incorrect trials were excluded from the data analyses, dipole analyses were no longer reliable having less than the required amount of correct trials per condition. For the exact localization of neuronal origins fMRI studies are even more precise, providing a lower time solution than ERP analyses e.g. [Harris, 08] [Henson, 08]. This also refers to the somewhat contradictory hemispheric asymmetries found for the ERE. In Experiment I, II (unfamiliar face mask), III (recognition session 1 –semantic decision task), when the view was the same or changed from prime to target) a right hemispheric lateralization was found, whereas in Experiment III in recognition session 2 the ERE was more pronounced in the left hemisphere for frontal and profile targets. This makes a meaningful interpretation concerning a lateralization with respect to viewpoint-dependent and viewpoint-invariant information processing impossible. Left hemispheric lateralization was found for part-based rather than whole-based information and viewpoint-invariant rather than viewpoint-dependent information processing e.g. [Pourtois, 05] [Rossion, 00a].
The results of Experiment III need replication. A repetition priming effect for frontal targets primed by their unknown profile view was not demonstrated before to my knowledge. The ERE´s although weak, indicate viewpoint-invariance in face recognition, as validated by the differences in GFP.
Statistical analyses of the presented data are based on correctly answered trials of only 16 participants. A less distinctive stimulus material, the encoding task, a rather short consolidation phase and the tasks difficulty might have led to a higher error rate and hence, to trial exclusion. Therefore, to enhance the acquisition and recognition rate in follow up studies a priori to the encoding task distinctiveness ratings should be performed to exclude those faces that are less distinctive [O'Toole, 98] [Wickham, 00]. Moreover, the encoding task itself by means of the learning session has a large influence on the recognition rate [Bonner, 03b] [Bernstein, 02]. The more individual or deeper the encoding (e.g. face's pleasantness as opposed to gender decisions) the better the recognition rate. Finally, the consolidation time between encoding and retrieval plays a major role for the transfer of facial representations due to LTM e.g. [Herzmann, 07] [Leveroni, 00] [Okada, 03]

[Tanaka, 06]. A consolidation time longer than 24 hours as in Experiment III might contribute as well to a higher recognition rate.
The recognition task influences the recognition rate [Guo, 05]. Guo et al. [Guo, 05] demonstrated that the face-name association was harder to remember correctly than the familiarity of the learned face itself. A semantic recognition task (home town classification) was used to reduce the number of conditions when conditions of same and changed view were compared. Still, a familiarity decision task might have led to a higher recognition rate and hence, to more correct trials available for data analyses. Still, based on the results found by Joyce & Kutas [Joyce, 05] that indicate the ERE as a correlate of implicit repetition priming as it was independent of explicit recognition, the inclusion of incorrect trials in data analyses can be considered as a way to enhance experimental power. Beside the problems concerning the studies at present and particularly Experiment III, variations of the experimental design itself are conceivable as follows. During the process of learning, when a face occurs repeatedly the structural representation alters from being an inflexible viewpoint-specific coding of a face to a very flexible representation that can be used across a range of transformations in the facial image. These processes depend on the view that was learned as they provide the information for generalization across view changes. Results in this thesis support O'Toole et al. [O'Toole, 98] and Valentine et al. e.g. [Valentin, 01] who looked in detail at the pattern of responses to different faces and concluded that there are two separable components that contribute to the recognition performance at differing viewpoints. A configuration-based component that correlates with performance between frontal and ¾ views, and a feature-based component that correlates with performance between ¾ and profile views. Thus, beside extreme changes in viewpoint as used in Experiment III the EREs sensitivity towards changes from ¾ view to frontal and ¾ view to profile view has to be studied. The ¾ view provides information that is detectable after a view change of 45° to the related frontal or profile view. Repetition priming of the ¾ view by its unknown frontal or profile view would provide a direct comparison of these to components of face recognition as supposed by O'Toole et al. [O'Toole, 98].

4.4 Relevance of the data

In the present thesis the question of viewpoint-sensitivity of the ERE and the consolidation of structural codes (configuration and features) within a single representation was

approached by exploring the ability of the human visual system to generalize recognition from a single familiarized frontal or profile view to the unfamiliar profile or frontal view respectively.

The present study allowed conclusions about viewpoint-independence in face recognition in that the prime view was previously unknown. Hence, repetition priming in the view-changed condition cannot be interpreted by interpolation between multiple two-dimensional images that are already stored in memory.

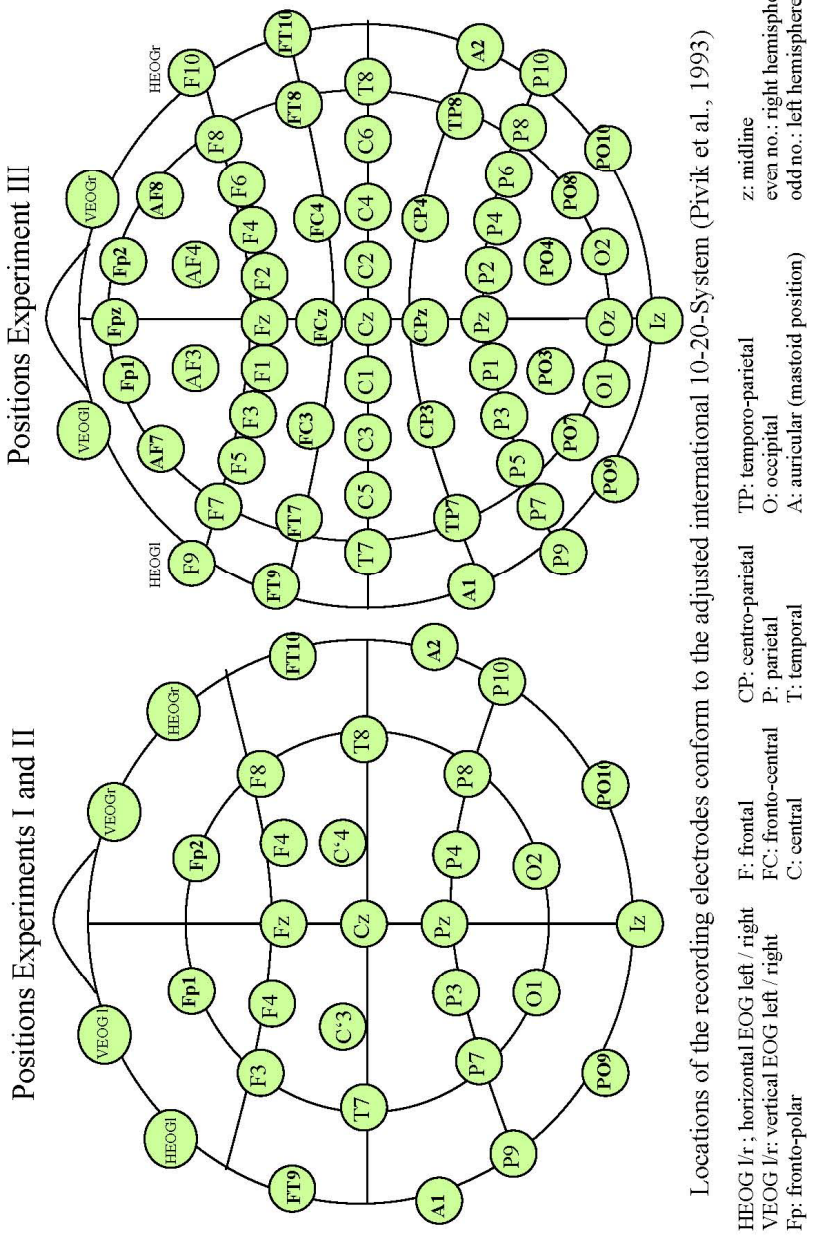
The view same condition was compared to the view change condition that exceeded 40° deviance with respect to the frontal or profile target. Thus, two different recognition strategies – recognition by configuration and recognition by features e.g. [O'Toole, 98] [Valentin, 01] were compared directly. A repetition priming paradigm with backward masking by an unfamiliar face was used (and tested in Experiment I and II) the EREs can be interpreted on a representation-based level. Taken together, for the first time, Experiment III provides a direct comparison between facial representations of frontal and profile targets and an analysis of their viewpoint-dependency. A representation-based ERE was demonstrated for frontal and profile targets primed by the same view and for frontal targets primed by their unknown profile view.

The thesis at present provides answers to the question about the dimensions and the description, or set of description of a face, linked within FRUs as suggested by Bruce and Young [Bruce, 86c], that are necessary before object-centred recognition can occur: second order relations by means of configuration of features along the horizontal and the vertical axis as well as unique features to be recognized even across large changes in viewpoint [O'Toole, 06].

In summary, face recognition across changes in viewpoint involves the processing of both viewpoint-dependent as well as viewpoint-invariant information provided by one particular view of an individual face.

APPENDIX

A) Recording positions of the scalp electrodes for recording the EEG



Locations of the recording electrodes conform to the adjusted international 10-20-System (Pivik et al., 1993)

HEOG l/r ; horizontal EOG left / right
VEOG l/r: vertical EOG left / right
Fp: fronto-polar
F: frontal
FC: fronto-central
C: central
CP: centro-parietal
P: parietal
T: temporal
TP: temporo-parietal
O: occipital
A: auricular (mastoid position)
z: midline
even no.: right hemisphere
odd no.: left hemisphere

B) Handedness inventory - German version of the Edinburgh inventory (Oldfield, 1971)

HÄNDIGKEITSFRAGEBOGEN

EXPERIMENT: _____ VPN.-NR.: _____ HQ:_____

Name :_____ Beruf : _____

Alter : Geschlecht : männlich ☐ weiblich ☐

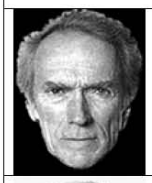
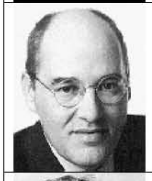
Bitte geben Sie die Hand an, mit der Sie bevorzugt die folgenden Tätigkeiten ausführen. Tragen Sie dafür ein + in die entsprechende Spalte ein.
Wenn die Bevorzugung der Hand so stark ist, daß Sie nur unter Zwang die andere Hand benutzen würden, tragen Sie bitte ++ in das entsprechende Feld ein. Sollten Sie nicht sicher sein, welcher Hand Sie den Vorzug geben, tragen Sie bitte in **beiden** Spalten ein + ein.
Einige Tätigkeiten verlangen den Gebrauch beider Hände. In diesen Fällen ist in Klammern angegeben, für welchen Teil der Tätigkeit die bevorzugte Hand angegegeben werden soll. Bitte beantworten Sie alle Fragen und lassen Sie nur dann eine Zeile frei, wenn Sie keinerlei Erfahrung mit dieser Tätigkeit haben.

Tätigkeit	**links**	**rechts**
1 Schreiben		
2. Zeichnen		
3. Werfen		
4. Schere		
5. Zahnbürste		
6. Messer (ohne Gabel)		
7. Löffel		
8. Besen (obere Hand)		
9. Streichholz anzünden (Streichholz)		
10. Schachtel öffnen (Deckel)		
I. Mit welchem Fuß kicken Sie bevorzugt?		
II. Welches Auge benutzen Sie, wenn Sie nur eines benötigen?		

Händigkeit des Vaters : Rechts ☐ Links ☐
Händigkeit der Mutter : Rechts ☐ Links ☐
Linkshänder in der Familie bekannt?: Ja ☐ Nein ☐

C) Questionnaire for stimulus selection Experiment I (in extracts)

Bitte kreuzen Sie an, welche der abgebildeten Personen Sie kennen, und welche Ihnen nicht bekannt sind. Geben Sie bei einer Ihnen bekannten Person deren Namen an oder woher Sie die Person zu kennen glauben. Wie sicher ist Ihre Entscheidung für bekannte als auch unbekannte Personen?
Vielen Dank für Ihre Mitarbeit!

Person	bekannt	unbekannt	Woher bekannt? (evtl. Namen)	Ich bin mir sicher 2 = sicher 1 = vielleicht 0 = nicht sicher
				
				
				
				
				
				

D) Questionnaire for selection of participants for Experiment I and II

(Stimuli used in Experiment I are labeled with "I", stimuli used in Experiment I and II are labeled with "I/II")

Würden Sie sich zutrauen, folgende (öffentlich bekannte) Personen am Gesicht zu erkennen?

Person	**Ja**, würde ich am Gesicht erkennen.	**Nein**, würde ich nicht am Gesicht erkennen.	Ich bin mir nicht sicher.
Fritz Kuhn I/II			
Hertha Däubler-Gmelin I/II			
Sabine Leutheusser-Schnarrenberger I/II			
Peter Struck I/II			
Johannes Rau I/II			
Egon Krenz I/II			
Richard von Weizsäcker I/II			
Bill Gates I/II			
Erich Honnecker I/II			
Jim Carrey I/II			
Nixon I/II			
Boris Jelzin I/II			
Fred Astaire I/II			
Hildegard Knef I/II			
Angela Merkel I/II			
Wolfgang Schäuble I/II			
Harald Schmidt I/II			
Manfred Krug I/II			
Till Schweiger I/II			
Didi Hallervorden I/II			
Rex Gildo I/II			
Rod Stewart I/II			
Reinhardt Mey I/II			
Nicolas Cage I/II			
Wynona Ryder I/II			
Gwyneth Paltrow I/II			
Maria Carrey I/II			
George Clooney I/II			
Sandra Bullock I/II			
Sean Connery I/II			
Queen Mom I/II			
Meg Ryan I/II			
Arnold Schwarzenegger I/II			
Sylvester Stallone I/II			
"Agent Scully" I/II			
Kate Winslet I/II			
Victoria Beckham I/II			

Person	**Ja**, würde ich am Gesicht erkennen.	**Nein**, würde ich nicht am Gesicht erkennen.	Ich bin mir nicht sicher.
Hugh Grant I / II			
Ricky Martin I / II			
Hillary Clinton I / II			
Drew Barrymore I / II			
John BonJovi I / II			
Pamela Anderson I / II			
Patsy Kensit I / II			
Hannelore Kohl I / II			
Ruth-Maria Kubitschek I / II			
Michael Stich I / II			
Karl Marx I / II			
Ulrich Wickert I / II			
Terence Hill I / II			
Howard Carpendale I / II			
Dieter-Thomas Heck I / II			
Elizabeth Taylor I / II			
Dieter Hildebrandt I / II			
Günter Rexrodt I / II			
Charles Brauer I / II			
Helmut Kohl I / II			
Günther Grass I / II			
Marcel Reich-Ranicki I / II			
John Major I / II			
Helmut Schmidt I / II			
Boris Becker I / II			
Sabine Christiansen I / II			
Bud Spencer I / II			
Gerhard Depardieu I / II			
Horst Tappert I / II			
Karl Dall I / II			
Wolf Biermann I / II			
Harald Juhnke I / II			
Uwe Barschel I / II			
Woody Allen I / II			
Walter Ulbricht I / II			
Regine Hildebrandt I / II			
Willi Brandt I / II			
Walter Sedlmeyer I / II			

Person	**Ja**, würde ich am Gesicht erkennen.	**Nein**, würde ich nicht am Gesicht erkennen.	Ich bin mir nicht sicher.
Loriot I/II			
Nina Hagen I/II			
Theo Waigel I/II			
Björn Engholm I/II			
Rita Süssmuth I/II			
Marilyn Monroe I/II			
Gerhard Schröder I/II			
Jürgen Möllemann I/II			
Lena Thier			
Oskar Lafontaine I/II			
Charlie Chaplin I/II			
Margarethe Schreinemarkers II			
Rudolf Scharping II			
Gregor Gysi II			
Alice Schwarzer II			
Steffi Graf II			
Lothar Späth II			
Grace Kelly II			
Kurt Russell II			
Götz George II			
Günther Jauch II			
Ronan Keating II			
Henry Maske II			
Christian Ströbele II			
Renate Schmidt II			
Kim Basinger II			
Matt Damon II			
Johnny Depp II			
Alec Baldwin II			
Pennelope Cruz II			
Liv Tyler II			
Angelina Jolie II			
Thomas Gottschalk II			
Uma Thurman II **Christiane Paul** II			
Maria Schrader II			
Timothy Dalton II			
Mickey Rourke II			
Babara Becker II			
Heinz Harald II **Frentzen**			
Jan Ullrich II			
Anna Kurnikova II			

Person	**Ja**, würde ich am Gesicht erkennen.	**Nein**, würde ich nicht am Gesicht erkennen.	Ich bin mir nicht sicher.
Gabi Bauer"			
Jennifer Aniston"			
Claudia Roth"			
Friedrich Merz"			
Franz Müntefering"			
Wolfgang Thierse"			
Jürgen Trittin"			
Günter Verheugen"			
Otto Schily"			
Sean Penn"			
Franka Potente"			
Jack Nicholson"			
Anthony Hopkins"			
Klaus Wowereit"			
Wladimir Putin"			
George W. Bush"			
R.W. Fassbinder"			
James Dean"			
Catherine Zeta-Jones"			
Alfred Biolek"			
Berti Vogts"			
Jürgen Klinsmann"			
Lothar Matthäus"			
Oliver Bierhoff"			
Tony Blair"			
Wayne Mullholand			
Hans Eichel"			
Udo Jürgens"			
Moritz Bleibtreu"			
Claudia Schiffer"			
Prince Charles"			
Mr. Bean"			
Arafat"			
Jean-Paul Belmondo" Romy Schneider"			
Jennifer Lopez"			
Franziska von Almsick"			
Pierre Brice"			
Saddam Hussein"			
H.- D. Gentzscher"			
W.I. Lenin"			
Joachim Kroll"			

Person	**Ja**, würde ich am Gesicht erkennen.	**Nein**, würde ich nicht am Gesicht erkennen.	Ich bin mir nicht sicher.
Katarina Witt "			
Mario Adorf "			
Dominic Horwitz "			
Klaus Kinski "			
Jan Josef Liefers "			
Sascha Hehn "			
Veronika Ferres "			
Thekla Carola Wied "			
Senta Berger "			
Esther Schweins "			
Corinna Harfouch "			
Wil Smith "			
Denzel Washington "			
OJ Simpson "			
Nadja Auermann "			
Stefan Raab "			
Whitney Houston "			
Tori Amos "			
Michael Jackson "			
Sigourney Weaver "			
Neve Campbell "			
Audrey Hepburn "			
Emmanuelle Beart "			
Iris Berben "			
Senta Berger "			
Antonio Banderas "			
Wolfgang Niedecken "			
Verona Feldbusch "			

Vielen Dank für Ihre Mitarbeit!!

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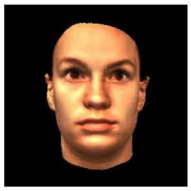
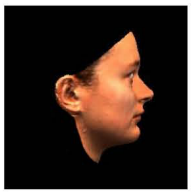
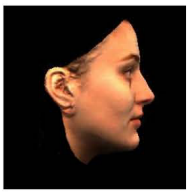
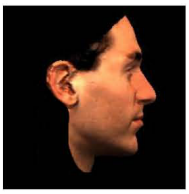
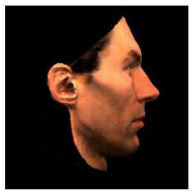
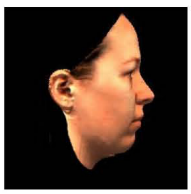
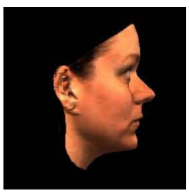
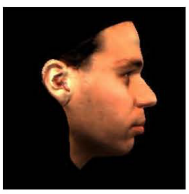
E) Examples of stimulus material Experiment III Part 1 and 2

Stimuli as used in Experiment III (in extracts)

A total of 64 stimuli had to be memorised prior to the experiment by classification to hometowns "Rome" or "Paris" (including 32 frontal faces and 32 profile faces, half male, half female).

Rome				
Paris				
Rome				
Paris				

F) Task instructions – Experiments I, II, III

Experiment I	Experiment II	Experiment III / Part 1	Experiment III / Part 2
Folgend werden jeweils nacheinander drei Gesichter präsentiert. Entscheiden Sie bitte per Tastendruck immer nur für das jeweils LETZTE Gesicht, ob es sich um eine öffentlich bekannte Person handelt oder nicht. Eine Namenszuordnung ist NICHT wichtig! Bitte reagieren Sie so schnell und genau wie möglich. Vielen Dank!	Folgend werden jeweils nacheinander drei Bilder präsentiert. Entscheiden Sie bitte per Tastendruck immer nur für das jeweils LETZTE Portrait, ob es sich um eine inländische oder ausländische Person handelt. Eine Benennung ist NICHT wichtig! Bitte reagieren Sie so schnell und genau wie möglich. Vielen Dank!	Folgend werden jeweils nacheinander drei Gesichter präsentiert. Entscheide bitte per Tastendruck immer nur für das jeweils LETZTE Gesicht, ob es sich um eine gelernte Person aus Rom oder Paris handelt. Bitte reagiere so schnell und genau wie möglich. Vielen Dank! Es folgen jetzt zwei Übungsblöcke mit jeweils den Gesichtern, die Du im Profil oder aus der Frontalansicht gelernt hast. Hier bekommst Du noch Rückmeldung über Deine Antwort, in den folgenden 4 Testblöcken nur noch bei zu langsamen Reaktionen.	Folgend werden jeweils nacheinander drei Gesichter präsentiert. Entscheide bitte per Tastendruck immer nur für das jeweils LETZTE Gesicht, ob es sich um eine gelernte Person (aus Rom oder Paris) handelt oder um eine, die Du vorher nicht gelernt hast. Eine Städtezuordnung für die gelernten Gesichter ist NICHT wichtig! Bitte reagiere so schnell und genau wie möglich. Vielen Dank! Es folgt jetzt ein Übungsblock. Dann schliessen sich 2 Testblöcke an. Im Übungsblock bekommst Du noch Rückmeldung über Deine Antwort, später nur noch bei zu langsamen Reaktionen.
Bitte reagieren Sie auf ein bekanntes Gesicht mit dem linken Zeigefinger (linke Taste) auf ein unbekanntes Gesicht mit dem rechten Zeigefinger (rechte Taste).	Bitte reagieren Sie auf eine inländische Person mit dem linken Zeigefinger (linke Taste) auf eine ausländische Person mit dem rechten Zeigefinger (rechte Taste).	Bitte reagiere auf ein Paris-Gesicht mit dem linken Zeigefinger (obere Taste) auf ein Rom-Gesicht mit dem rechten Zeigefinger (untere Taste).	Bitte reagiere auf ein gelerntes Gesicht mit dem linken Zeigefinger (obere Taste) auf ein ungelerntes Gesicht mit dem rechten Zeigefinger (untere Taste).
Wechsel der Antworttasten!	Wechsel der Antworttasten!	Wechsel der Antworttasten!	Wechsel der Antworttasten!
Bitte reagieren Sie auf ein bekanntes Gesicht mit dem rechten Zeigefinger (rechte Taste) auf ein unbekanntes Gesicht mit dem linken Zeigefinger (linke Taste).	Bitte reagieren Sie auf eine inländische Person mit dem rechten Zeigefinger (rechte Taste) auf eine ausländische Person mit dem linken Zeigefinger (linke Taste).	Bitte reagiere auf ein Paris-Gesicht mit dem rechten Zeigefinger (untere Taste) auf ein Rom-Gesicht mit dem linken Zeigefinger (obere Taste).	Bitte reagiere auf ein gelerntes Gesicht mit dem rechten Zeigefinger (untere Taste) auf ein ungelerntes Gesicht mit dem linken Zeigefinger (obere Taste).

G) Instructions to the learning task Experiment III

Ablauf des Gesichterlernens – Überblick

Was?

32 Gesichter Paris; davon 16 frontal und 16 im Profil

32 Gesichter Rom; davon 16 frontal und 16 im Profil = insgesamt 64 Gesichter

Wie?

Lernteil 1:

8 Gesichter frontal (Rom) nacheinander

8 Gesichter frontal (Paris) nacheinander

Test der zuletzt gezeigten 16 Gesichter

8 Gesichter profil (Rom) nacheinander

8 Gesichter profil (Paris) nacheinander

Test der zuletzt gezeigten 16 Gesichter

Test über alle 32 Gesichter des ersten Lernteils

Lernteil 2:

8 Gesichter frontal (Paris) nacheinander

8 Gesichter frontal (Rom) nacheinander

Test der zuletzt gezeigten 16 Gesichter

8 Gesichter profil (Paris) nacheinander

8 Gesichter profil (Rom) nacheinander

Test der zuletzt gezeigten 16 Gesichter

Test über alle 32 Gesichter des 2. Lernteils

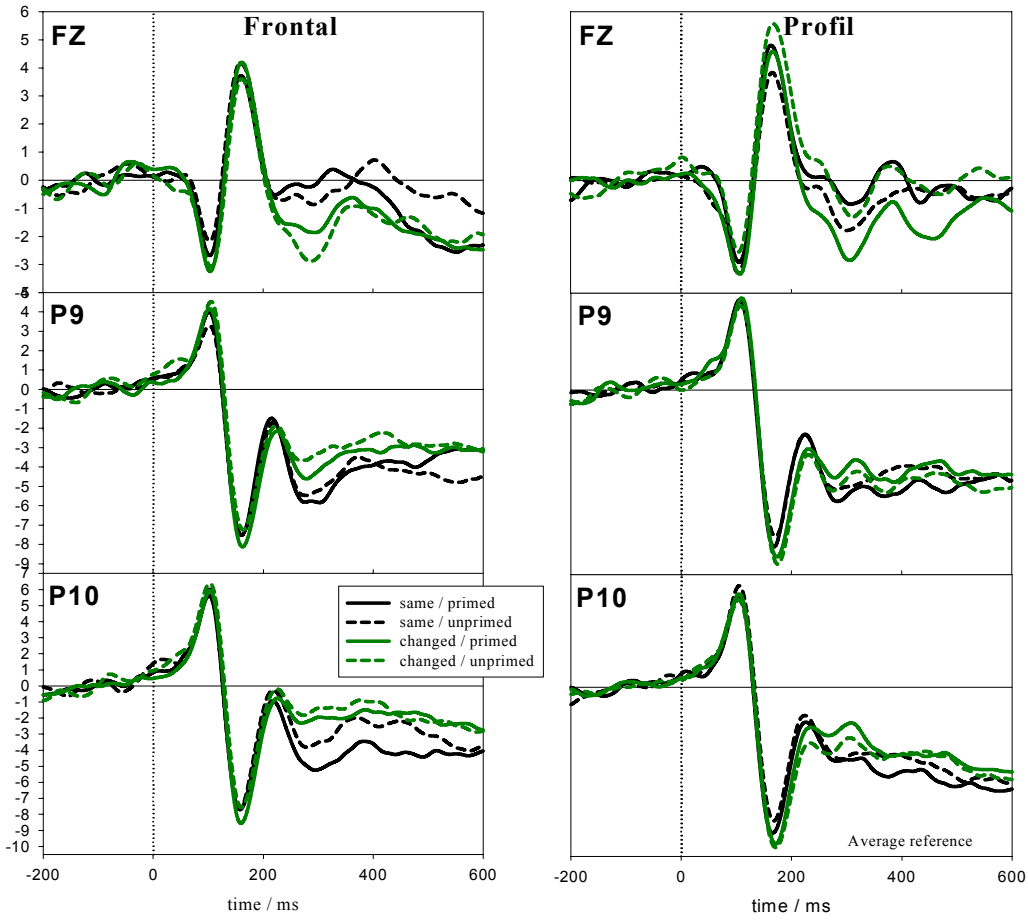
Nochmaliges „Überfliegen“ aller Gesichter auf der Übersicht.

Abschliessender Testteil über alle 64 Gesichter!

(Falsche Antworten werden angehangen.)

Danke für Deinen Einsatz und natürlich viel Erfolg!

H) Experiment III / recognition session 1: ERPs for the view same / view changed conditions for primed and unprimed targets



I) EIDESSTATTLICHE ERKLÄRUNG

Hiermit erkläre ich an Eides Statt, dass ich diese Dissertationsschrift selbstständig und eigenhändig, ohne unerlaubte Hilfe verfasst, andere als die angegebenen Quellen nicht benutzt und die den benutzten Quellen wörtlich oder inhaltlich entnommenen Stellen als solche kenntlich gemacht habe. Darüber hinaus ist mir bekannt, dass bei der Verwendung von Inhalten aus dem Internet, die mit dem Datum sowie Angabe der Adresse zu kennzeichnen sind.

Diese Arbeit hat keiner anderen Prüfungsbehörde vorgelegen. Ich habe mich nicht anderwärts um einen Doktorgrad beworben, ebenso besitze ich in keinem Promotionsfach einen Doktortitel.

Die dem angestrebten Verfahren zugrunde liegende Promotionsordnung ist mir bekannt.

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Berlin, den 29.05.2008

Peggy Dörr

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